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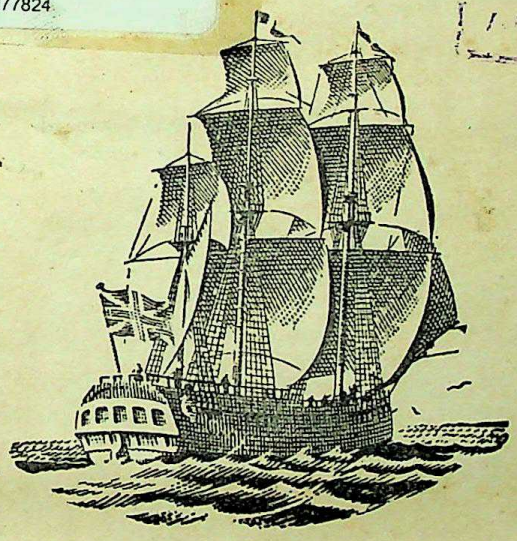

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	H. DINGLE, D.Sc., A.R.C.S., is Professor of History and Philosophy of Science at University College, London, and Vice-President of the Royal Astronomical Society. His scientific work has been chiefly concerned with spectroscopy, relativity, and the philosophical aspects of science.	
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	H. J. T. ELLINGHAM, Ph.D., A.R.C.S., F.R.I.C., is Secretary of the Royal Institute of Chemistry. His scientific interest lies in various aspects of chemical thermodynamics; he has also been strongly attracted to administration. In both these respects he has a close association with Imperial College, London.	
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	J. GRAY, C.B.E., M.C., Sc.D., LL.D., F.R.S., is Professor of Zoology in the University of Cambridge. As a zoologist he has a particular interest in cytology.	
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	J. W. HUNKIN, O.B.E., M.C., M.A., D.D., is Bishop of Truro. Besides possessing high academic qualifications in both mathematics and theology, he is an accomplished field botanist.	
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	J. S. HUXLEY, M.A., D.Sc., F.R.S., has recently been appointed Executive Secretary of the Preparatory Commission of the United Nations' Educational, Scientific, and Cultural Organization. He was formerly Secretary of the Zoological Society of London and has a wide interest in the biological sciences.	
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	SIR NELSON JOHNSON, K.C.B., D.Sc., A.R.C.S., is Director of the Meteorological Office of the Air Ministry, London.	
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	J. KENDALL, M.A., D.Sc., F.R.S. (London and Edinburgh), is Professor of Chemistry in the University of Edinburgh and General Secretary of the Royal Society of Edinburgh.	

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G. F. MARRIAN, D.Sc., F.R.I.C., F.R.S., is Professor of Chemistry in relation to Medicine in the University of Edinburgh. His main scientific interest is in the chemistry of the sex-hormones.

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L. H. MATTHEWS, M.A., Sc.D. (Cantab.), holds a Research Fellowship in the University of Bristol. He has travelled widely in investigating the morphology and physiology of mammals, and spent four years with the *Discovery* expedition.

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A. T. R. MATTICK, B.Sc., Ph.D., Dip.Agr., is head of the Bacteriology Department of the National Institute for Research in Dairying. He has a particular interest in the bacteriological examination of dairy products and in the application of statistical methods to biological problems.

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N. F. MOTT, M.A. (Cantab.), F.R.S., is Melville Wills Professor of Theoretical Physics in the University of Bristol. His scientific interests are primarily in problems relating to atomic physics, metals, and photographic emulsions.

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SIR CLIFFORD PATERSON, O.B.E., D.Sc., F.R.S., is Director of the Research Laboratories at Wembley of the General Electric Company. His main scientific interests are in problems connected with light and lighting.

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F. L. ROSE, B.Sc., Ph.D., has since 1942 been in charge of speculative chemical research in chemotherapy for Imperial Chemical Industries.

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G. SMITH, M.Sc., F.R.I.C., is Research Demonstrator in Biochemistry at the London School of Hygiene and Tropical Medicine. In 1945 he was President of the British Mycological Society. His main scientific interests are in problems relating to textiles, the taxonomy of moulds, and antibiotics.

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T. A. STEPHENSON, D.Sc. (Wales), is Professor of Zoology in University College, Aberystwyth. He was in charge of the Reef Section of the Great Barrier Reef Expedition, 1928–9. His biological interests include the ecology of the seashore, sea anemones, and corals.

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T. WALLACE, M.C., D.Sc. (Dunelm.), F.R.I.C., is Director of the Long Ashton Research Station and Professor of Horticultural Chemistry in the University of Bristol. He is interested primarily in the study of nutrition of fruit trees, including studies of soils and of the chemistry and physiology of the hardy fruits.

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F. S. WALLIS, D.Sc., Ph.D., F.G.S., is Director of the City Museum, Bristol, and Honorary Editor of the *Museums Journal*.

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J. W. T. WALSH, M.A., D.Sc., M.I.E.E., is a member of the Photometry Section of the National Physical Laboratory at Teddington. He has a wide interest in problems relating to lighting. He is a Past President of the Illuminating Engineering Society.

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C. W. WARDLAW, Ph.D., D.Sc., F.R.S.E., is Professor of Cryptogamic Botany in the University of Manchester. He has a particular interest in the botany of tropical fruits and in their transport and storage.

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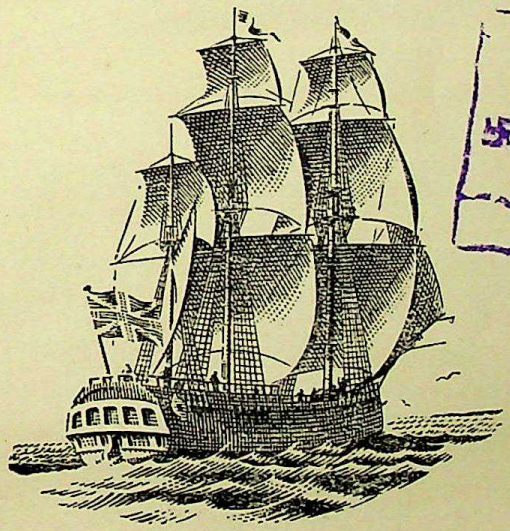

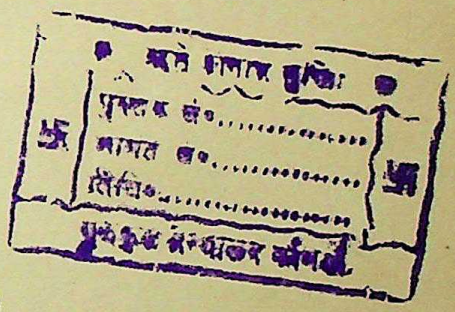

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	G. E. FOGG, B.Sc., Ph.D., was born in 1919 and was educated in London and at St. John's College, Cambridge. He has carried out research on nitrogen fixation by blue-green algae and on the control of weeds by chemical methods. He is Lecturer in Plant Physiology at University College, London.	
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	D. V. N. HARDY, B.Sc., Ph.D., A.R.I.C., is Principal Scientific Officer at the Chemical Research Laboratory, Teddington. His scientific interests include the study of organic catalytic reactions under high pressure.	
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	N. H. HARTSHORNE, M.C., M.Sc., Ph.D., F.R.I.C., has been Lecturer in Chemistry at University College, Swansea, since 1927. His scientific interests include the application of optical crystallographic methods to chemistry and the study of the kinetics of polymorphic transformations.	
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	ARTHUR HOLMES, D.Sc., A.R.C.S., F.R.S., is Regius Professor of Geology and Mineralogy in the University of Edinburgh. His chief scientific interests are problems of petrology and petrogenesis and the applications of the methods of radio-activity to geology.	
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	O. B. LEAN, B.Sc., D.I.C., is a member of the Central Agricultural Control Department of Imperial Chemical Industries. During the late war he was Chief Locust Officer in Cairo. He has studied locust control in many parts of the world.	

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	A. J. P. MARTIN, M.A., Ph.D., is now engaged in research for Boots Pure Drug Company Limited. He is particularly interested in chromatography and played a leading part in the development of partition chromatography.	
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	R. E. PEIERLS, C.B.E., M.A., D.Sc., D.Phil., F.R.S., is Professor of Applied Mathematics at Birmingham. He played a leading part in the wartime atomic energy projects and is now consultant to the Atomic Energy Department of the Ministry of Supply.	
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	JEAN TIMMERMANS, D.Sc., is Professor of Physical Chemistry and of the History of Chemistry at the *Université Libre* in Brussels. He has carried out extensive research on the stoichiometry of organic compounds.	
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	C. H. WADDINGTON, M.A., Sc.D., F.R.S., is Professor of Animal Genetics in the University of Edinburgh and Chief Geneticist to the National Animal Breeding Research Organization of the Agricultural Research Council. During the late war he was Scientific Adviser to the Commander-in-Chief of Coastal Command, Royal Air Force.	
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	C. M. YONGE, D.Sc., F.R.S., is Regius Professor of Zoology in the University of Glasgow. His chief scientific interest is in marine biology, which he has studied at research stations in many parts of the world.	

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The future of man

The deliberate release of atomic energy comes as the climax of two centuries of science. It may well prove to be the most momentous event in the history of mankind. There are many men, and they not the least wise, who see no hope for the human race except by calling a complete halt to scientific research. Their imagination, fed by the appalling horrors of the last few years, pictures only too vividly the universal catastrophe likely to follow the use of the new source of energy for purposes of warfare. That the possibility of such catastrophe exists it would be idle to deny; but the suggested remedy is neither practicable nor desirable. It is inherent in the nature of man that he should seek new realms for exploration, both in thought and in action, and no legislation could stifle the urge. On the other count, it must be recognized that scientific knowledge has at least as great potentialities for good as for evil, and that to cut off science would be to cut off the main hope of human betterment. What is happening in the present phase of history is that science is creating problems at a rate greater than that at which they can be solved; but it is a counsel of despair to assume that such disparity will not in time be adjusted.

In considering the world-problems of today it is easy to lose sight of the fact that man is a product of organic evolution, and that evolution is a dynamic process still in operation. Any attempt to descry beyond the immediate future must therefore reckon with the possibility of further evolutionary changes, and from such a standpoint we may be able to form a sounder judgment of current difficulties. In the present issue we publish an article by Dr Julian Huxley on the subject of evolution. One of the most interesting conclusions that he reaches concerns man himself. Morphologically, man has changed comparatively little since the date of the earliest known human remains. He has not, as it were, spent his evolutionary capital in branching out into highly specialized new forms. In all other important types of organism this kind of specialization has ultimately come to a standstill, further changes resulting only in the formation of new species and genera and not in completely new types. It therefore seems possible that in man, whose history as measured in geological units is still very brief, such changes are yet to come.

Man differs from all other organisms in possessing highly-developed reasoning powers which allow him considerable control over his environment. As a result, purely morphological changes are unlikely to have much effect upon his history —to fly it is not necessary for him to grow wings, and he can cross the seas without swimming. *Per contra*, inasmuch as he depends more and more upon his intellectual endowment any evolutionary changes in this respect might be of fundamental significance.

It is difficult to arrive at any estimate of the probability of these changes. From written records and from investigations of early civilizations the conclusion seems inescapable that, during the last five or six thousand years, the human mind has not appreciably improved in ability. The sages of ancient Egypt, Assyria, and Babylonia, the philosophers of classical antiquity, and the intelligentsia of India, China, and Islam appear to have been as capable of intensive and fruitful thought as their best modern counterparts. True, their thought was directed in different directions from those we tend to follow today; but there is no reason to suppose that, had they had at their disposal our tradition and store of knowledge, men of two or three thousand years ago could not have made the discoveries that are at once the glory and the peril of the twentieth century. The reasoning power was certainly there, but the pabulum for its exercise and

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nourishment had not yet been accumulated. That the average man of 1946 is very much better informed than his predecessors of even a century ago must surely be ascribed to better methods for the dissemination of knowledge rather than to an increased power of assimilating it. And it can hardly be disputed that one of the chief reasons for our present troubles is this wide extension of knowledge to people whose minds are not sufficiently cultured to make proper use of it.

It therefore seems likely that, while the possibility of a sudden evolution of man's mental capacity and quality cannot be altogether ruled out, the chances are that he will continue to make discoveries—and use or misuse them—with very much the same level of intelligence as he possesses today. There is, however, another possible factor to be considered. Hitherto there has been no sign that the progress of science is being hindered by the limitations of the human brain, but we may legitimately surmise that sooner or later a stage will be reached when the mind is inadequate to effect further advance. The continued existence of warfare may perhaps be taken as an indication that this stage has indeed already been arrived at, so far as morals and ethics are concerned; its eventual attainment in the quest for scientific knowledge would then be equally sure.

These reflections lead us to the interesting speculation whether it may in the future be possible to improve the human brain artificially. Events of the last few years, in all branches of science, demonstrate that such a speculation is not to be ranked as wildly fantastic: the scientist's dream of yesterday has recently been in the habit of coming true today. Substances—such as amphetamine—are already known which, on the basis of simple intelligence tests, appear temporarily to increase the power of reasoning, while the intellectual stimulation afforded by cocaine has long been a commonplace in the sensational novel. All drugs of this kind hitherto discovered suffer from serious disadvantages which would preclude their general use even were their mental effects of substantial value; but it is by no means unlikely that coming generations of biochemists may synthesize substances in which the beneficial reactions are enhanced and the deleterious reduced to a negligible minimum.

Chemical stimulation is of course only one of several ways in which it is conceivable that the capacity of the human brain may be better equipped for the tasks it will be required to undertake. Recent progress in experimental biology suggests that chromosome control may be a powerful tool in shaping the forms of life, and in due course it might prove applicable to man himself. In any case, whenever and however it is brought about, we have every reason for believing that man will be able to improve upon natural man, for such an achievement would be no more of a miracle than much that he has already accomplished.

The doubt remains whether science has so far outstripped the development of moral character as to render the years immediately ahead the most critical and dangerous period in the history of the world. That there should be a variety of opinions on this point is not surprising. The shocking devastation caused by the two atomic bombs dropped over Japan raises hopes in some minds that all nations will in future abstain from war, if only because victor and vanquished would probably be engulfed in a common ruin. Others, with a fatalistic bias, are pessimistic about the common sense of man, and foresee the suicide of civilization and indeed of man, with the instrument that represents his supreme effort of logical thought. Only time will show which of these two schools is correct—if either; but it is perhaps unduly gloomy to suppose that, even in an atomic war, the survivors would be so few that the human race would be completely unable to resuscitate civilized life. Many great civilizations of the past were destroyed or sank into decay, but these events, grievous and calamitous as they must have been at the time, have not prevented the more or less steady development of mankind as a whole. If the growth of civilization is an evolutionary process, we should remember when considering it that evolution is no longer regarded as continuous but rather as arising from many different points and proceeding along several paths, sometimes divergent, sometimes convergent. The world may now be standing at one of the junctions.

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Species and evolution

JULIAN S. HUXLEY

Less than a century has elapsed since Charles Darwin enunciated the evidence for organic evolution in his celebrated *Origin of Species*. Today the fundamental truth of the theory is firmly established, and biologists are no longer concerned with proof of the reality of evolution; the problem is to elucidate its mechanism. In this article Dr Huxley discusses current views on the subject. He reaches the interesting conclusion that, except in the case of man himself, the most important evolutionary changes have probably run their course.

THE PROBLEM AND ITS EXTENT

When Darwin wrote his great work, he called it the *Origin of Species* because that was then the crux of evolution. Either species were fixed and permanent in their characters, as they had been created in the beginning 'each after their kind,' in which case evolution was ruled out; or they could change into quite different types, in which case evolution must be accepted.

Today the position is entirely different. Evolution is generally accepted as a fact; we know that species change. Biologists are now trying to discover what they can about the different modes of evolution, the different kinds of species, and the different ways in which they may originate.

A main distinction which has emerged is between long-term trends on the one hand, leading usually to an improvement of general type, and short-term diversification on the other. The difference between the two can be illustrated from any modern mammalian type. The horse stock, for instance, showed a steady increase in efficiency of hoofs and of grinding teeth throughout tens of millions of years. That was a long-term trend. But today the horse, the zebras, and the asses merely ring minor changes on the general perfected equine plan (figure 1), and in every epoch the type was diversified into many different species, all at approximately the same level of the main trend.

What is a species? In one sense it is just a group of similar animals or plants which it has been agreed to distinguish by means of a Latin name. Thus the birds popularly called Lesser Redpolls are assigned to the species *Carduelis flammea*, *Carduelis* being the name of the genus, *flammea* of one of the species within it. But this assigning of specific names is not merely arbitrary. Species are also natural groups, which can usually be defined by a combination of the following criteria. First, their members inhabit a geographical area which is in accord with the idea of a single common origin for the whole. Secondly, they either interbreed, or are potentially capable of interbreeding, with each other. Thirdly, they possess certain distinctive common characters. Fourthly, they usually do not interbreed with other specific groups, or, if they do so, fertility is reduced.

There are exceptions to all these criteria; they have different weight in different forms; and there are borderline cases where evolution has taken a group half-way to specific distinctness. We must expect a compromise between the human need for pigeon-holing facts and the variety and fluidity of nature. Yet in well-worked groups there is remarkable agreement as to what should be called species. Thus in birds, Ernst Mayr estimates that fewer than 1 per cent. of the thousands of named species are doubtful or disputable.

The extent of the species problem can be realized when we discover that something like a million species of animals have already been named, and that new discovery is still adding to the list, and at an increasing, not a decreasing, rate.

However, more interesting than semi-philosophical disputes about definitions are the investigations which are showing how groups actually vary in nature and how biological discontinuities arise in them, and may be accentuated.[1]

Let us first look at diversification within species. I spoke earlier of the Lesser Redpoll. This breeds in Britain and much of central Europe. In northern Europe, and also in Siberia and Canada, the breeding redpolls, though very similar, are definitely paler and a little bigger: their popular name is Mealy Redpoll. In Greenland they are still larger, but not so pale as the Mealy. These three geographical groups are too alike to be called species; they are therefore called *subspecies*,

[1] The species problem is still fluid. A brief essay such as this inevitably fails to do justice to the complexity of nature, or to take account of various points of view held by other biologists.

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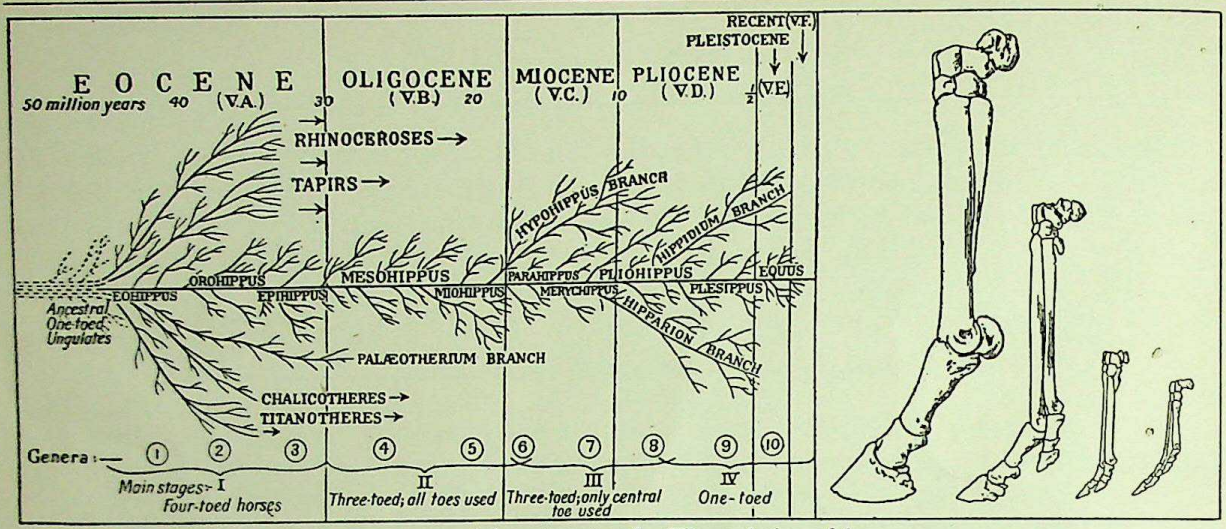

FIGURE 1 – *A long-term trend. The evolution of horses.*

(a) left. The horse stock took something like fifty million years to evolve from the original odd-toed ungulates. (The time-scale of the Pleistocene and recent periods is magnified relative to the rest of the diagram.) Numerous side branches were produced and became extinct, but the main trend was continuous.

(b) right. Stages in the trend: a series of left fore-feet. Right, Eohippus with three of its four toes visible (fifth, fourth, and third). Next, Mesohippus with three longer toes, all used. The fifth digit is reduced to a small splint bone. Next, Merychippus. It possesses hoofs, but the fourth and second digits are small and lifted off the ground, the third (central) digit is enlarged. Left, a modern horse (Equus). The second and fourth digits are reduced to splints and have lost their hoofs. The central digit is much enlarged and has a big hoof. The general trend is towards greater size and rapid running.

(*From* The Science of Life, *3-volume edition. By permission of H. G. Wells, J. S. Huxley, and G. P. Wells.*)

and given a third name—the Lesser Redpoll is *Carduelis flammea cabaret;* the Mealy is *C. f. flammea;* and the Greenland is *C. f. rostrata* (figure 3). Another set of high northern redpolls is quite definitely distinct, in having an unstriped white rump and belly. It is therefore assigned to a different species, *C. hornemanni.*

GEOGRAPHICAL SUBSPECIES

Distinct forms on islands cannot interbreed freely with their neighbours; but when they are so similar that they can be presumed to be capable of fertile crossing, they also are called subspecies. Thus in Britain, the wrens on St. Kilda are uniformly larger, heavier-billed, and with more barring than those of the mainland.

In the diversification of species by geography, several different factors are at work. There is on the one hand adaptation to local conditions; on the other there is the effect of isolation, which allows much more rapid divergence of groups; and there is the size of the group—in isolated small populations non-adaptive 'accidental' changes may become established.

With regard to the species of North American Deermouse, *Peromyscus polionotus*, Sumner has given us some very interesting facts from Florida (figure 4). On an isolated reef of white sand, a distinct, almost white, subspecies is found. The coastal strip, about 35 miles wide, has lightish sandy soil and is inhabited by a moderately pale subspecies. The inland area has heavy dark soil, with a dark subspecies, its colour nicely adapted to that of the soil. The white form is a protective adaptation to the white sand. But its origin has been made possible by breeding isolation; for on the equally white beach of the mainland shore, the mice are merely rather paler than further inland.

Where the pale and dark mainland subspecies meet, there is a belt, only a few miles wide, where the average colour changes very rapidly from pale to dark. But besides this change in average, there is to be noted a sharp increase in variability. This can only mean that two distinct types here interbreed, with resultant recombination of characters. There is clearly a general adaptation of both the subspecies to soil colour. In addition, it seems that each is 'internally adapted,' through the development of its own distinctive complex of genes, or hereditary units, making for vigour, fertility, and so on. When two such gene-complexes are crossed, most of the recombinations will be less well-adjusted, and their spread will be discouraged by natural selection; this will keep the hybrid zone narrow.

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There are two complications. The coastal form seems to have expanded recently on to the edge of the dark inland soil, along the seaward side of which there is a narrow belt of white sand. Thus so far as colour goes, selection will be making the coastal form paler on one margin, darker on the other, and a gradient of characters (or 'cline' as it has been called) is the result.

Quite a number of birds and mammals show this general feature of stabilized subspecies remaining fairly constant over comparatively large regions, and being separated by narrow belts in which the character changes rapidly.

There are other cases where the inhabitants of a continuous area differ in different parts of it sufficiently to warrant being called subspecies, but no sharp steps, no narrow intergrading zones, have been found. This may sometimes be due to insufficiency of facts—as more specimens accumulate and the steps are looked for, they will turn out to be there after all. But nature is almost perversely varied, and sometimes continuous slight variation seems to operate over very large stretches. This is true for the sharp-tailed grouse over the great plains of North America.

ECOTYPES

In regard to plants, botanists generally prefer to use the word *ecotype* to denote the lower units of which species are made up. The primary meaning is a form or group adapted to a particular set of environmental conditions. It was the Swedish botanist Turesson who first gave currency to the term. For instance, in the grass *Poa alpina* in Scandinavia, he showed that there were three distinguishable ecotypes, from alpine, subalpine, and lowland habitats. These differ in various visible ways, but also in more important ecological characters, such as water-requirement and time of flowering. The basic differences are hereditary.

Sometimes the ecotypes are just like subspecies in higher animals. Thus a team of Californian botanists, under the leadership of Clausen, has been growing ecotypes of various plant species at experimental stations at various heights. To take one example, the potentilla, *P. glandulosa*, has a well-marked climatic ecotype in the Coast Range, and another in the Sierra Nevada foothills. The two are separated geographically and are obvious subspecies. When we get higher up in the Sierra, however, things become rather different. After a certain altitude a hill-meadow ecotype overlaps with the foothill form. However, even in the overlap zone the two are kept separate by their ecological requirements: the foothill form is practically restricted to the dry hillsides, the higher one to moist meadows.

Gregor in Scotland has described an extension of this kind of arrangement in the common sea-plantain, *Plantago maritima*. In many areas, there is a steady gradation from waterlogged, salty mud to dry, less maritime conditions. The plantains then also show a corresponding gradation in various characters—average height, for example, ranging from about 20 cm. to nearly 50 cm. The evidence goes to show that the environment seems to act as a sieve. A great range of different ecotypes must be produced, but they are sifted out by their requirements, so that even a rapid gradation in the environment is reflected in a gradation in the plant's characters: ecotype here is therefore quite different from subspecies.

To return to the Californian potentilla, it was found that, at still greater heights, there were a subalpine and an alpine ecotype. The one was taller and later-flowering, the other definitely dwarfish and early-flowering. But in this case the two ecotypes grade gradually into each other over a belt of considerable width.

These examples will show some of the complexities of the picture. Very broadly, we may say that the species of higher animals tend to be divisible into geographical sub-groups, those of higher plants into ecological or habitat sub-groups, though there are exceptions, and though broad ecological adaptation will often coincide with geographical separation. The difference, so far as it is real, is presumably related to the more random methods of fertilization and of dispersal in the plants, which facilitate sifting by habitat.

GEOGRAPHICAL ISOLATION

It is when isolation is at work that the divergence of groups can, and often does, become accentuated. This is true both for the formation of subspecies and for full species. In addition, small populations, as Professor Sewall Wright has shown, are liable to what we may call evolutionary accident. In them, many old genes may die out entirely, and useless (or even deleterious) mutations or gene-combinations may become fixed, owing to mere chance.

A pretty example of this comes from lizards on the Adriatic. Sinking of the coast has isolated lizard populations on a number of islands. As we might expect, the degree of difference of the island populations from the mainland form increases roughly with the time they have been

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separated (as measured by the depth of water between island and mainland). But it also does so with decrease in the size of the island, and therefore of the size of the population.

Similarly, Dr Uvarov tells me that quite small groups of flightless grasshoppers which occur in isolated patches in arid regions may be sharply distinct from each other.

Quite apart from the size of population, isolation encourages diversification. An excellent example is the little Malayan Mouse-deer. This is represented by a single subspecies of uniform type over the whole of Sumatra and Borneo; but on the islands of the Rhio Linga archipelago, with less than 1/150th of the area, no fewer than seven distinct subspecies have evolved.

Not merely subspecies but obviously full species may develop through isolation. Thus in Britain, our red grouse is clearly derived from the same stock as the willow grouse of continental Europe. Yet it differs not merely in such minor features as its dark wing-feathers, but in not changing colour to white in winter. It is accordingly ranked as a distinct species, with the name *Lagopus scoticus*. It is interesting that no other British bird has reached more than subspecific difference.

This seems to be due to lack of time, for, on old archipelagoes, the process may go further. Mayr illustrates this from the Barking Pigeons (*Ducula*) in the Pacific (figure 2).

Once isolation has allowed the evolution of distinct forms which will not interbreed, these species may spread out and come to overlap in their distribution, instead of replacing each other in different geographical areas like mere subspecies. The two forms generally differ somewhat in adaptation and way of life. Thus our closely related willow-warbler and chiffchaff now live side by side in Britain, but are adapted to somewhat different habitats. There has been a real diversification of the original leaf-warbler type—though where the original separation occurred we do not know.

LARGE-SCALE DIVERSIFICATION

When combined isolation and diversification continue for long periods, we can sometimes see genera and families being evolved. A single group may radiate out in many directions, which are often adaptive, though more or less accidental differences also occur. The classical case of this is provided by the groundfinches of the Galapagos archipelago. They are classical because they were one of the chief reasons which forced Darwin to believe in evolution.

The Galapagos archipelago comprises some nine larger and a number of smaller volcanic islands. The nearest mainland is the west coast of South America, over 600 miles distant. The groundfinches (*Geospizidae*) are a distinct family, confined to the archipelago (and to Cocos Island):

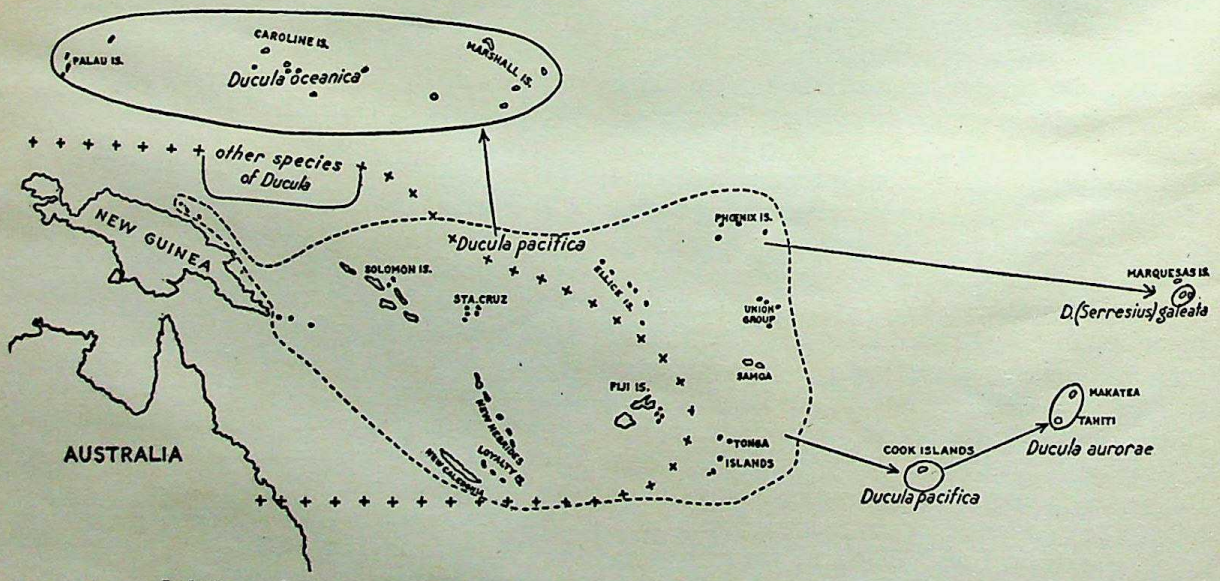

FIGURE 2 – *Isolation and divergence. The Barking Pigeon of Polynesia,* Ducula pacifica, *has given rise to closely related species to the north and on Tahiti. On the isolated Marquesas Islands it has produced a species so different in beak-shape that it was originally classified in a different genus.*

(*From E. Mayr,* Systematics and the Origin of Species. *By courtesy of Columbia University Press.*)

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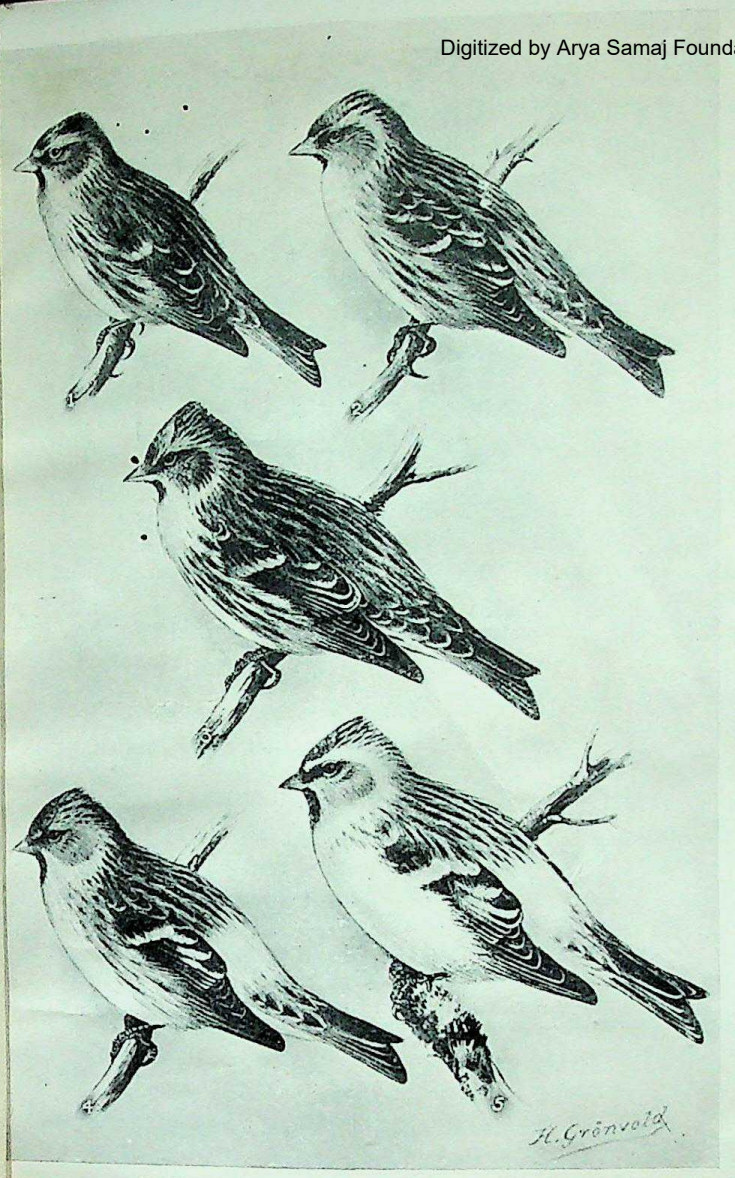

GURE 3 – *Species and geographical subspecies of redpoll* (*see text*).
) *to* (3) Carduelis flammea. (1) *Lesser Redpoll*, (2) *Mealy Redpoll*,
) *Greenland Redpoll.*
) *and* (5) Carduelis hornemanni. *Subspecies from Greenland, and from*
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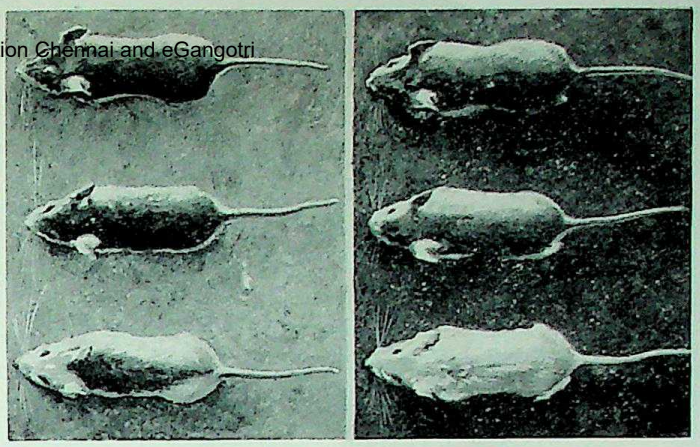
rom H. F. Witherby, et al., Handbook of British Birds. *By courtesy of Messrs. H. F. & G. Witherby.*)



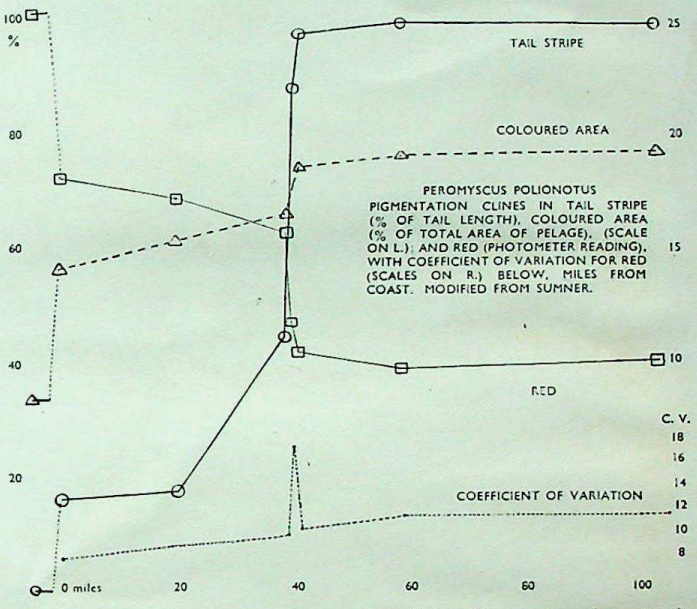


FIGURE 4 – *Subspecies in an American Deermouse* (*see text*). (*a*) *top. The inland, coastal, and island subspecies. On the left, against a background of white sand, on which the island form lives; on the right, against the dark soil from the area of the inland form.*

(*b*) *The accompanying graph shows the effect of selection and isolation on pigmentation. The island subspecies* (*left-hand point*) *is isolated. The coastal subspecies grows darker until the zone of admixture and increased variability is reached* (40 *miles from the coast*). *The inland subspecies is almost uniform.* (*The amount of red decreases with increasingly dark colour.*)

(*a*) *From* The Science of Life (*3-volume edition*). *By permission of H. G. Wells, J. S. Huxley, and G. P. Wells.*

(*b*) *After J. S. Huxley in* Bijdragen tot de Dierkunde (*Leiden*), 1939.

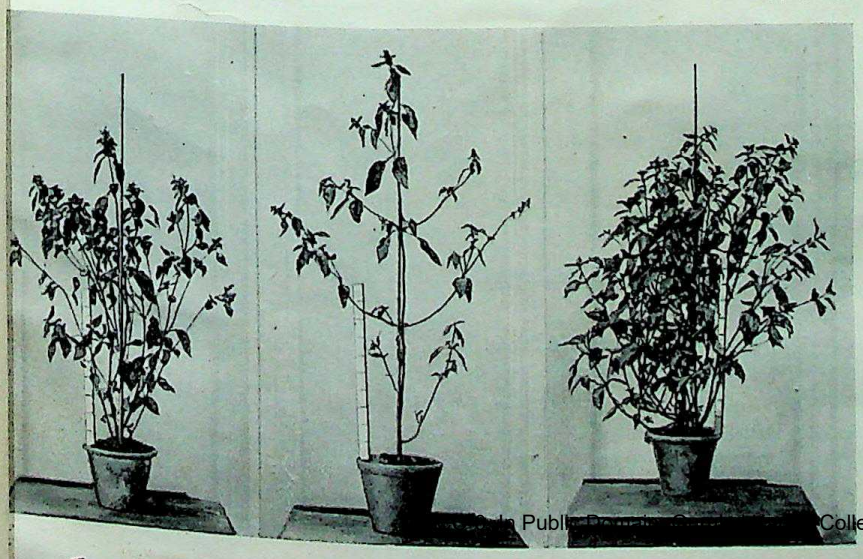


FIGURE 5 (*left*) – *The synthesis of a species.* (1) *and* (3) Galeopsis speciosa *and* G. pubescens, *two wild labiates, each with* ($n = 8$) *chromosomes. The hybrid between them was almost sterile, but eventually doubled the number of its chromosomes, and became fertile. This new fertile tetraploid species is practically indistinguishable from another wild species,* G. tetrahit.

(*From A. Müntzing*, Hereditas (*Lund, Sweden*), *Vol.* 14. *By courtesy of the author and publisher.*)

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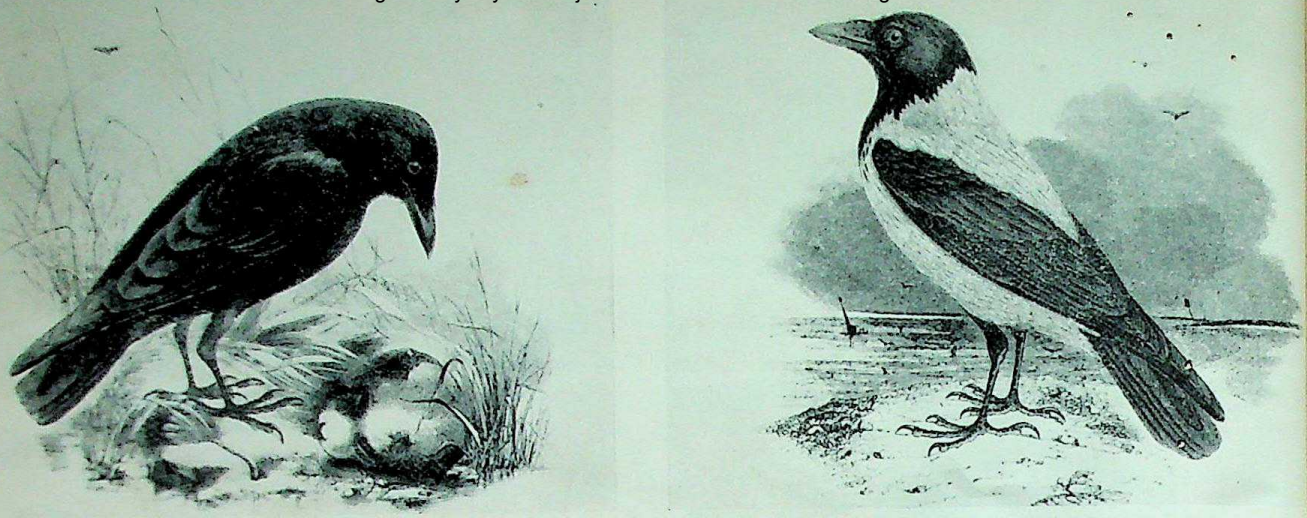

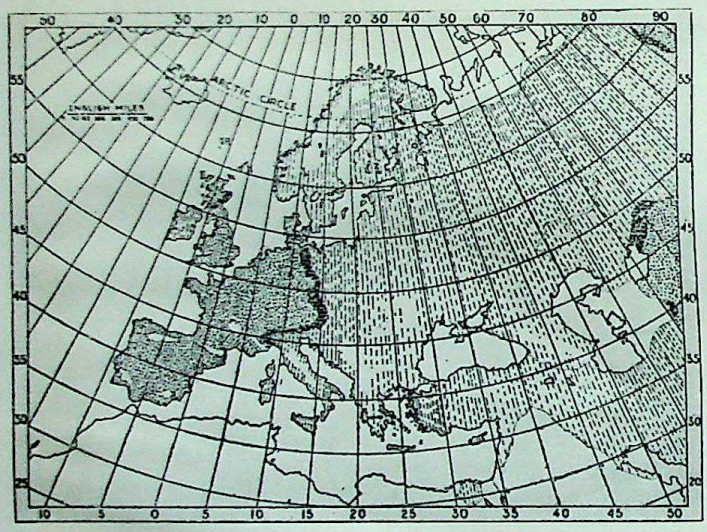

FIGURE 6 – *Borderline species.*

(a) top. The Carrion and Hoodie crows are very distinct in colouration.

(b) left. But where they have re-met after the ice-age they interbreed and give fertile hybrids. The range of the Carrion crow is indicated by dots, that of the Hoodie by vertical lines, and the belts of interbreeding by dark shading (see text).

(a) From Yarrell's British Birds. *(b) From H. F. Witherby,* et al., Handbook of British Birds. *By courtesy of Messrs. H. F. and G. Witherby.*

FIGURE 7 – *An allotetraploid species may be more successful than its parents.* Spartina townsendii *(see text) has been able to colonize areas over which the indigenous parent species* S. stricta *was unable to spread.*
(a) left. Early stages in the colonization of bare mud in Poole Harbour. *(Photograph by R. V. Sherring.)*
(b) right. Approximately the same view, thirteen years later. *(Photograph by F. W. Oliver.)*

(From A. G. Tansley, The British Islands and their Vegetation. *By permission of the author.)*

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they do not occur on the mainland. The entire family must have arisen from a single pair of some kind of finch accidentally blown out to sea. They have since evolved into five well-marked genera, with nearly 20 species (figure 8).

Even greater diversification has taken place among the sicklebill family (*Drepanididae*), confined to the Hawaiian archipelago (and Laysan Island). They have evolved into 18 distinct genera (with some 40 species), including not merely seed-eaters and insect-eaters, but nectar-suckers with special tongues, and a unique 'woodpecker' type (*Heterorhynchus*) which has a long upper mandible adapted to pry away bark, and a short lower mandible for pecking out grubs in the wood. Some authorities consider that they show diversification in more adaptive directions than any other family of birds.

On oceanic archipelagoes, there seems to be another factor at work besides isolation: since the fauna is a very restricted one, being confined to the descendants of comparatively few accidental stragglers, there is less competition. This biological low pressure makes it easier for new adaptive specializations to arise. If there had already been woodpeckers in Hawaii, we can be pretty sure that the woodpecking adaptations of *Heterorhynchus* would not have been evolved.

Something similar appears to happen when enemies are fewer: low predator-pressure may act in the same sort of way as low competition-pressure. The best example of this comes from the little Cichlid fish of the East African lakes. All these lakes are isolated, and in each there are

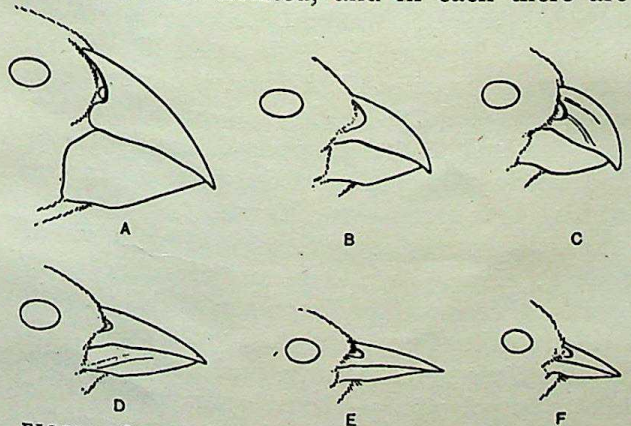

FIGURE 8 – *Divergent radiation in the groundfinches. On the Galapagos archipelago five different genera have been evolved.* (A) Geospiza, *includes large-billed seed-eaters.* (B) Platyspiza, *mainly leaf-eating.* (C) Camarhynchus, *mainly insectivorous.* (D) Cactospiza, *uses a twig to pry insects out of wood.* (E) *Is a similar slender-billed form from Cocos Island.* (F) Certhidea, *warbler-like.*
(*After H. S. Swarth. By courtesy of* Biological Reviews, *Cambridge.*)

Cichlid species peculiar to that lake, or *endemics* as the biologist calls them. The big predaceous fish *Lates* and *Hydrocyon* have managed to invade some of these lakes, but not others. Where they are absent and predator-pressure is low, many more endemic species, adapted to more ways of life, have evolved. Apparently new evolutionary ventures do not get the same chance of survival when opposed by the streamlining pressure of powerful enemies.

ECOLOGICAL ISOLATION

If such numerous and diverse types have arisen in a continuous body of water, we must suppose that in animals geographical isolation is not the only avenue to achievement of the rank of full species, and that isolation by habit or habitat is also possible. It is difficult to visualize the process, and some authorities refuse to admit it. However, there are certain cases where it seems definitely established. Thus among insects restricted to one or a few food-plants, we may find so-called 'biological races' with different food-preferences. For example, the ermine moth has one race adapted to apples, the other to hawthorn and blackthorn. The apple form usually starts its larval life as a leaf-miner, the other not. Given a choice of food-plants the larvae of both races show an 80 to 90 per cent. preference for their own; and an almost equally high fixation is shown by the female moths in their egg-laying preferences. Caterpillars forced to eat the 'wrong' food give moths which are generally undersized and often infertile. Finally, the mating-preference between males and females of the same race is twice as strong as that between those of different race. Thus, though the two races may coexist in the same area, they are halfway to separation as distinct species. In other insects, this type of divergence has produced full species.

We know that many pests of cultivated plants have arisen through a change in food-preference. For instance a bug, *Plesicoris rugicollis*, which in nature is confined to willows, in 1918 began turning its attention to apples, and later the apple race became quite a pest.

How a species gets on to a new food-plant, we do not know. But once a new source of food has been successfully colonized, there is some ecological isolation, and the new strain may persist and evolve. For the adults which emerge are 'conditioned,' in the psychologists' phrase, to the smell of the plant they have fed on as larvae, and will often prefer it to the original species. Thorpe

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has made experiments in flavouring the food of fruit-fly grubs with different chemicals and finds that, even in this more mixed feeder, a considerable conditioning of the adults' egg-laying preferences takes place.

Thorpe's results are a beautiful experimental confirmation of the principle of 'Organic Selection' put forward long ago by Baldwin and by Lloyd Morgan. They suggested that a change of habits, without any inherited alteration, might often be the first step in evolution. The strain would be held, more or less firmly, by its habits in a new niche, until such time as mutation and selection could provide a hereditary constitution adapted to the new environment.

CLOSE SPECIES

Sometimes when closely related species occupy the same area, the mating barriers between them seem to have been intensified by natural selection. Thus our familiar chiffchaff and willow-warbler are extremely alike in most ways, but differ strikingly in their song (occasionally the chiffchaff will add a warble to its unwarblerlike two notes, indicating that these are a recent acquisition).

Often, however, no such obvious distinctions arise, and only painstaking research will show that what was at one time regarded as a single species is in reality two or more. Thus it was once believed that there existed one species of malaria mosquito in Europe—*Anopheles maculipennis*. Now it turns out that there are at least five or six reproductively isolated groups, i.e. species. These differ hardly or not at all in the adult, and very slightly in the larvae, but can all be distinguished by their egg-floats—in shape, colour, and pattern. They also differ in their habits, in the degree of their tolerance of salt-water, and in their capacity to transmit malaria to man.

Sometimes we can understand just how these almost identical species have come into being. The little brown tree-creepers of Europe really belong to two distinct species. The western, our *Certhia familiaris*, has a rather shorter beak and a longer and less bent hind-claw, and is slightly lighter-coloured than the eastern *C. brachydactyla*. They overlap over a broad zone in central Europe, but seem never to interbreed. Their distinctness was discovered by C. L. Brehm over a hundred years ago; but most ornithologists refused for some seventy years to believe that two creatures so alike could really be distinct species.

The explanation seems to be as follows. In the glacial period the spread of the ice split the range of the original single creeper species in two. A south-western and a south-eastern group were isolated. In their isolation they became just different enough not to cross. So when the ice finally receded they did not merely spread back again but could overlap without losing their separateness.

Perhaps even more striking are the chains of subspecies which are continuous, yet whose terminal links will not breed with each other (see figure 9). The entire group is one and two species simultaneously—or, if you prefer it, two of its subspecies behave as species when they meet.

When groups re-meet after separation, their divergence may not have proceeded all the way towards full separation, and they will still interbreed. The crows provide an example from our own islands. During the ice age the eastern European group must have evolved the striking pied grey-and-black plumage of the Hoodie, while the Carrion crow of the south-western area stayed black.[1] The two forms have now re-met, and where they meet form a narrow band of hybrids of every type (figure 6). In Europe the interbreeding zone runs south of the Alps and up to the western Baltic.

CROSSING AND CHROMOSOME-DOUBLING IN PLANTS

In plants, matters are more complicated, for what are undoubtedly quite separate species will not infrequently hybridize easily and give fertile offspring. Thus the purple-flowered lucerne (*Medicago sativa*) imported into Europe as a forage plant in the seventeenth century, seems speedily to have crossed with the indigenous yellow-flowered sickle medick (*M. falcata*). The hybrid has strange greenish-black flowers, is exceedingly variable (doubtless owing to Mendelian recombination), but as a group is more vigorous and fertile than either of its parents. In one region of France where lucerne has not been artificially kept up, only the hybrid has survived. Here we have a 'hybrid swarm' so distinct as to merit the separate specific name of *M. sylvestris*.

Plants differ from animals in yet another way, namely their much greater tendency to what is known as polyploidy—the reduplication of whole sets of chromosomes. The chromosomes are the carriers of the genes, which are strung out along their length. The entire hereditary constitution is cut up and divided among a number of chromosomes, the number being normally constant for

[1] A third group in south-eastern Asia also remained black.

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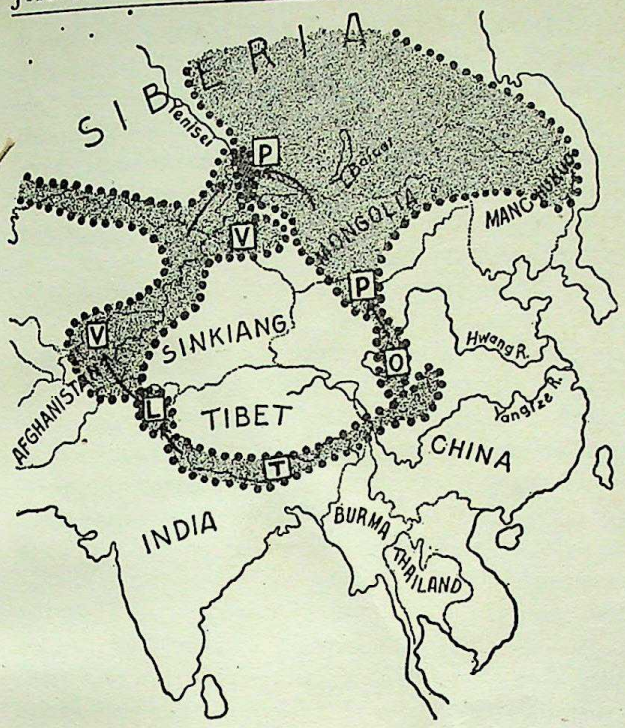

FIGURE 9 – *Subspecies diverging until interbreeding is no longer possible. In central Asia, the warbler* Phylloscopus trochiloides *forms a ring of five closely related subspecies, each intergrading with the next. However, where the two terminal subspecies*—Vizidanus (V) *and* Plumbeitarsus (P)—*have later come into contact, they overlap without interbreeding (cross-hatched area).*

(*From E. Mayr,* Systematics and the Origin of Species. *By courtesy of Columbia University Press.*)

any species. Typically there are two complete sets or packs of chromosomes in each cell of the body; before reproduction, these are sorted out so that each gamete (sexual cell) whether sperm (or pollen-grain) or egg, has one pack only.

The basic number of chromosomes in a single pack is conveniently denoted by n. The sexual cells will then contain n, the body cells $2n$. Now sometimes during cell-division the chromosomes may be doubled, but the cell-body fail to divide.[1] All the descendants of this cell will then have double the normal number of chromosomes, or $4n$; and the shoots and flowers so produced will be *tetraploid*, or four-fold in respect of their chromosomes. Doubling seems to be promoted by extreme conditions, notably cold. Such flowers, crossed with normals, will give $3n$ (triploid) offspring, and these will be sterile, since the chromosomes cannot be distributed to give complete sets in the sexual cells—there will be two of one kind of chromosome, one of another, and the result is a hopeless imbalance. Even if crossed with similar tetraploids, they will have somewhat reduced fertility, since there will be a fair proportion of sexual cells in which division will have distributed three of one kind of chromosome to some cells, and only one to others.

But many plants are capable of non-sexual reproduction—by suckers, bulbils, parthenogenesis, and so forth—and by these means the tetraploids may maintain themselves at first. They are likely to do so, for in difficult conditions they are often hardier than the normal $2n$ (diploid) type.[2] And, once they are established, selection may adjust various mechanisms of cell-division to increase their fertility. Triploids, however, will have to rely entirely on non-sexual methods.

Fresh doubling may later occur, giving $8n$, $16n$, $6n$, $12n$ forms, and so on. Whatever the details of origin, it is a fact that many plants exist in two or more forms which differ primarily in their 'ploidy.' The mountain anemone (*A. montana*), for example, has $2n$, $4n$, and $6n$ strains, practically indistinguishable to look at, but incapable of giving fertile or fully fertile offspring when crossed. There is thus *genetic isolation* within the species. But this may become translated into geographical terms. Thus in the cruciferous plant *Biscutella laevigata*, the original $2n$ type has been able to survive only in a few isolated areas. The $4n$ type, which may well have arisen in the first place owing to the cold, was also more cold-resistant and more generally vigorous; it now occupies a large continuous area across Europe, reaching a good deal further north than the $2n$ type. Sometimes the evidence suggests that the original $2n$ forms have been wholly unable to compete with the $4n$'s, and have simply died out.

Here is quite a new method of diversification. In animals, some degree of genetic isolation may come about through internal rearrangements of bits of the chromosomes (too complex to describe here), and if aided by geographical isolation may lead on to the separation of mutually infertile groups—true species—which will tend to resemble each other very closely.

CONVERGENT SPECIES-FORMATION: NETWORK CLASSIFICATION

The most surprising fact about plant evolution, however, is that definite new species can be formed abruptly, by the crossing of two other species followed by chromosome-doubling. We

[1] Or a gamete may be formed with the unreduced ($2n$) number of chromosomes.

[2] Chromosome-doubling also not infrequently produces an increase of size of the whole plant or of its organs.

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may call this convergent species-formation, as opposed to the usual splitting or divergence of one species into two or more.

The classical case is that of *Primula kewensis*, so called because it arose at Kew from a spontaneous cross between two well-known species, *P. verticillata* and *P. floribunda*. It was at first entirely sterile, but after some years of cultivation by cuttings, a single fertile shoot appeared. When examined, this was found to possess 36 chromosomes instead of the 18 of the rest of the plant and of both its ancestors. Before doubling, the hybrid had one pack of chromosomes from each parent. And these were so different that they would not work together properly. But after doubling it possessed two complete double packs; and now sexual reproduction with reasonably normal chromosome-pairing and normal development could take place (see also figure 5). A tetraploid produced thus is called an allotetraploid, as opposed to the autotetraploids or self-doublers previously considered.

Primula kewensis probably owes its survival to human aid. But *Spartina townsendii* shows what may occur (figure 7). *Spartina stricta* is a European rice-grass of salt-marshes. *S. alterniflora* is an American species whose seeds were accidentally brought over in ships' cargoes. The two seem to have crossed ($n = 28$) × ($n = 35$); but the resultant hybrid ($2n = 63$) must have been infertile until it doubled its chromosome-number to 126. This new tetraploid species is hardier than either parent, and is able to colonize tidal mud-flats where neither would previously grow.

The pink garden horse-chestnut arose in a similar way from a cross between the white-flowered European horse-chestnut and the American red buck-eye.

Polyploidy, auto- and allo-, singly and in combination, has undoubtedly played a large part in the evolution both of wild and cultivated plants.

Finally we must mention some groups, such as the blackberries and the willows, where sexual and asexual reproduction, hybridization, and both kinds of polyploidy are combined in such a way that an interlocking network of forms is produced, with lines of descent both converging and diverging. The results defy all attempt at ordinary pigeon-holing, so that the species-concept largely breaks down in such networks.

The only animal in which anything approaching this 'reticulate' evolution occurs is man. If man had been like other mammals, we can be sure that his major 'races' would have diverged along fully separate paths. But his restlessness and his psychological peculiarities have led to the original divergence being replaced by a steadily increasing amount of migration and intercrossing.

Between one and two million species of animals and plants are known. As we have seen, they differ in their mode of origin, their size, their structure and variability, their capacity to adjust themselves to new conditions or to become extinct. They clothe the world in diversity. New species and new adaptations are still being evolved, and contributing to this minor diversity of life. But what of the major diversity? Are new long-term trends still being initiated, which are capable of producing wholly new types of organism—as novel as the horse or the cat compared to the early mammals; as the warm-blooded mammal compared to its reptilian ancestor; as land animals compared to fish; as flowering compared to flowerless plants?

No one can give a certain answer. Yet it seems probable that life's major trends have run their course. It is a rule of evolution that new major types become dominant by branching out into lines of increasing specialization and that each specialization eventually comes to a dead end. Selection can push it no further along that line—it can merely ring minor changes upon the type by throwing off new species or genera. And when a new dominant type arises, it does so from an unspecialized member of the previously dominant group.

There is one exception to this—the human species. Man is now the dominant type of organism. He has remained unspecialized in structure. He has not radiated out into wholly separate lines. His new capacities for conscious thought and purpose, on which his biological dominance depends, give him the possibility of establishing a common pool of consciousness. His specializations are learnt, not inherited biologically. If he set his mind to it, he could control not merely his natural and his social environment but his future biological evolution.

The study of species is providing part of the essential knowledge which he must amass. During the last few decades, the advances in genetics, cytology, and other branches of biology have made a new, synthetic view possible. The patient and too often unrecognized labours of the museum classifiers are bearing fruit, and are being extended into the field and the experimental laboratory. Within a short space of time, the materials will be ready for a new Darwin to write another masterpiece on the subject—but the title will have to be not the *Origin*, but the *Origins of Species*.

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William Curtis, founder of *The Botanical Magazine*

J. W. HUNKIN

Scientific journals, as one of the main channels for the exchange of information and opinion, have played an important part in the development of science. It is appropriate that in this year, which sees the second centenary of his birth, we should remember the work of William Curtis, founder of *The Botanical Magazine*. This was one of the earliest botanical journals; its publication has not been interrupted since its first appearance in 1787, and in its own field it has established a reputation as one of the world's foremost periodicals.

William Curtis, founder of *The Botanical Magazine*, was born at Alton, in the English county of Hampshire, on 11th January, 1746. His father was a tanner and a member of the Society of Friends. At the age of fourteen, William was apprenticed to his grandfather, John Curtis, the surgeon-apothecary of Alton, whose premises were next door to the Crown Inn. An ostler employed at this inn had a remarkable knowledge of the wild flowers and the insects of the neighbourhood, and encouraged the boy in his taste for natural history. When he was twenty, William was sent to London, to assist an apothecary and to study at St. Thomas's Hospital; but natural history remained his chief interest, and on one occasion he was taken severely to task for paying three guineas for an engraving of the common nettle.

When his employer died he succeeded to his business, and a trade card declares that 'William Curtis, Apothecary, 51, Gracechurch Street, sells all sorts of drugs and chemical medicines.' Some years ago the Corporation of the City of London placed a plaque of blue encaustic on the wall of the tall building which now occupies the site:

'In a house on this site lived
WILLIAM CURTIS, Botanist,
B. 1746 – D. 1799.'

It is pleasing to observe that the plaque has survived the war undamaged.

In 1770 Curtis took a partner, and not long afterwards sold him the practice. In the next year, with the support of two London business men, Benjamin and Thomas White, brothers of the Rev. Gilbert White of Selborne, Curtis started a garden of about an acre in Grange Road, Bermondsey, for the cultivation and study of British plants.

This year, 1771, saw the first of Curtis's publications, a pamphlet of 44 pages with one plate. It was entitled *Instructions for collecting and preserving insects; particularly Moths and Butterflies*. This little work received the commendation of Mr Banks (afterwards Sir Joseph), and his friend and secretary, Dr D. C. Solander.

In 1772, Curtis was appointed Demonstrator of Botany to the Society of Apothecaries at Chelsea. It was his duty to show the young apprentices the medicinal plants in the Apothecaries' Garden, and to take them on botanical excursions in the neighbourhood. He threw himself into this work with great zest.

In May, 1775, there appeared the first number of the *Flora Londinensis*, 'A new and original Botanic Work, intended to comprehend all the Plants which grow wild in Great Britain, beginning first with those which are found *in the environs of London*.' Partly from lack of funds, and partly through pressure of other work, the numbers (which were priced at five shillings coloured and half a crown plain) appeared with an irregularity which exasperated the subscribers, and the sale seldom, if ever, exceeded three hundred copies. Of the seventy-two numbers, only two contained descriptions of plants from localities more than ten miles from London. The entire publication, which was ultimately bound up in two monumental volumes, was abandoned in 1798.

In 1777, Curtis resigned his appointment as Demonstrator, and in the same year published a students' edition of Linnaeus's *System of Botany*. Two years later, on 1st January, 1779, he opened a 'London Botanic Garden' at Lambeth Marsh. Subscribers of one guinea a year were entitled to walk in the Garden every day except Sunday, use the library, and introduce one person. Those subscribing two guineas could introduce more than one, either in person or by ticket, and receive

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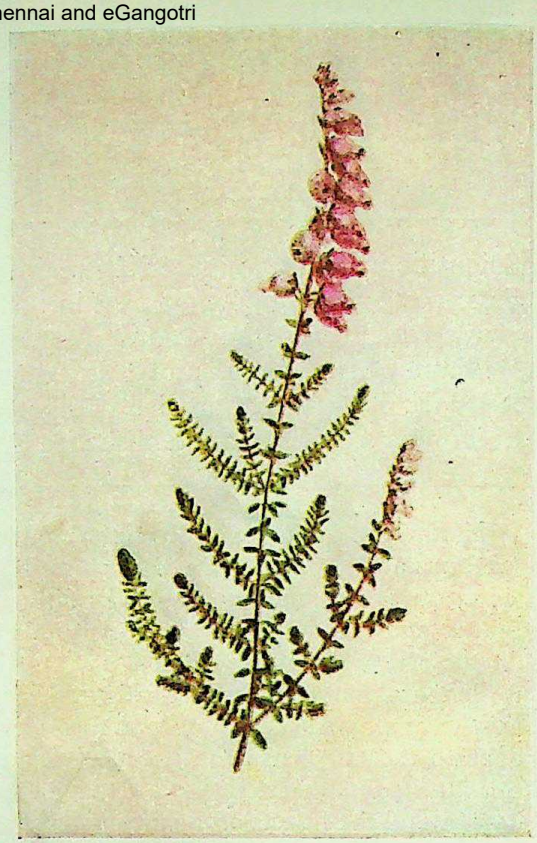
Iris persica (*t.*1).



Erica ciliaris (*t.*484).

Camellia japonica (*t.*42).

Jasminum officinale (*t.*31).

(*Illustrations taken from early volumes of* The Botanical Magazine.)

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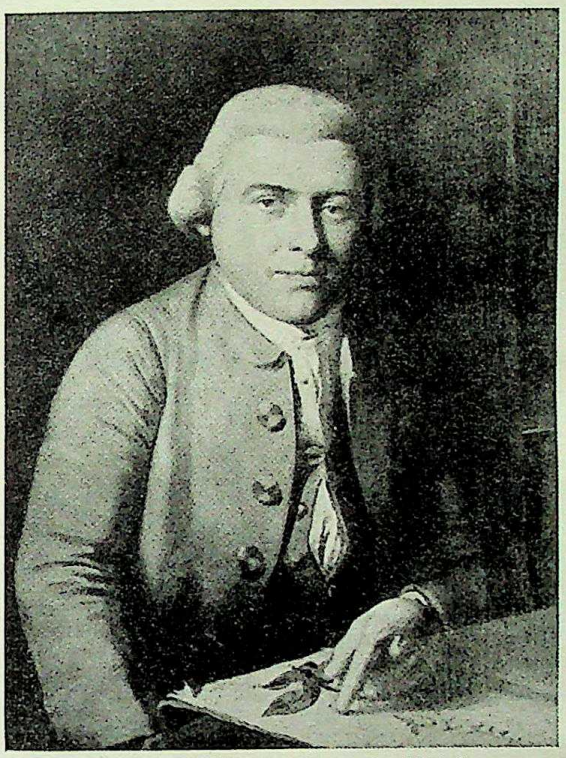
roots and seeds of such plants as could be spared without diminishing the necessary stock. A catalogue of the plants, about six thousand in number, was issued in 1783. It was divided into five sections: medicinal plants, culinary plants, common poisonous plants, agricultural plants, and British plants. It contained a list of persons to whom Curtis was indebted for plants to start the garden. This began with Mr Aiton of Kew, and included Sir Joseph Banks, the Rev. J. Lightfoot, the Rev. Dr Goodenough, Mr James Crowe of Norwich, Mr Thomas Woodward of Bungay, and several of the leading nurserymen such as Lee (who introduced the cultivation of the fuchsia into England) and Loddiges.

The need for such a garden will be appreciated when it is realized that at this time even the Physic Garden at Oxford was 'neglected and deserted' —I quote from a letter dated 21st May, 1778, written by a Mr J. Stokes of Worcester, who had just been to see it.

In 1782, great alarm was created by the appearance of vast numbers of the brown-tailed moth. 'In many of the Parishes of London, subscriptions were opened, and the poor people employed to cut off and collect the webs, at one shilling per bushel, which were burned under the inspection of the Churchwardens, overseers, or beadle of the parish. At the first onset of this business, four score bushels, it is stated upon creditable authority, were collected in one day, in the parish of Clapham. They were supposed to be the forerunner of the plague: even prayers were offered up in some churches, to deliver us from the apprehended calamity.'[1] Accordingly, Curtis published a monograph on the insect, price one shilling and sixpence, in which he clearly showed how ill-founded the alarm was.

It was five years later, in 1787, that Curtis began to issue what proved to be by far his most important publication, *The Botanical Magazine*, now often referred to as *Curtis's Botanical Magazine*. The inaugural number appeared on 1st February, with the title page shown overleaf.



Portrait of William Curtis by Wright.
(Reproduced by permission of the Royal Horticultural Society.)

In his preface to *The Botanical Magazine* Curtis lays down a principle which has been followed in the *Magazine* ever since:

'At the commencement of this publication, he had no design of entering on the province of the Florist, by giving figures of double or improved flowers, which sometimes owe their origin to culture, more frequently to the sportings of nature; but the earnest entreaties of many subscribers have induced him so far to deviate from his original intention as to promise them one at least of the Flowers most esteemed by Florists.'

Curtis used to say that the *Flora* brought him praise, but *The Botanical Magazine* brought him pudding—and eventually praise more abundant also. For the *Magazine* not only flourished during his lifetime but has continued to do so down to the present day, the latest volume to be published being Vol. CLXIV, 1944, and the last plate being numbered t.9666. It was originally issued in monthly numbers (octavo), each containing three plates and descriptions of plants and costing one shilling. It was the first illustrated botanical periodical, and was an immediate success. It had a sale of about 2,000 monthly copies, which soon increased to 3,000.

A brief letter (31st December, 1789) from Dr Goodenough, one of the founders of the Linnaean Society, and afterwards Bishop of Carlisle, illustrates the appreciation with which the *Magazine* was at once received:

'Dear C.U.R.,

'The Duchess of Portland begs that you would *immediately* upon receipt of this, send her the thirteenth number of the *Botanical Magazine* and ever afterwards the other numbers as they are published, on the very day on which they are published. You are to leave them at Burlington

[1] Dr R. J. Thornton, *Sketch of the Life and Writings of W. Curtis*, pp. 4, 5.

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THE
BOTANICAL MAGAZINE;
OR,
Flower-Garden Displayed:
IN WHICH
The most ornamental FOREIGN PLANTS, cultivated in the Open Ground, the Green-House, and the Stove, will be accurately represented in their natural Colours.
TO WHICH WILL BE ADDED,
Their Names, Class, Order, Generic and Specific Characters, according to the celebrated LINNÆUS; their Places of Growth, and Times of Flowering:
TOGETHER WITH
THE MOST APPROVED METHODS OF CULTURE.
A WORK
Intended for the Use of
Such LADIES, GENTLEMEN, and GARDENERS, as wish to become scientifically acquainted with the Plants they cultivate.

LONDON:
Printed by FRY and COUCHMAN, Upper-Moorfields,
For W. CURTIS, at his BOTANIC GARDEN, Lambeth-Marsh;
And sold by all Booksellers, Stationers, and News-Carriers, in Town and Country.
M DCC LXXXVII.

TO
MRS. MONTAGU BURGOYNE;
NOT LESS ESTEEMED
FOR HER
SOCIAL AND DOMESTIC VIRTUES,
THAN ADMIRED FOR THE
ACCURACY WITH WHICH SHE DRAWS,
AND THE
DELICACY WITH WHICH SHE PAINTS
THE
BEAUTIES OF FLORA,
THIS ATTEMPT TO UNITE
SYSTEMATIC KNOWLEDGE
WITH THE PLEASURES OF THE
FLOWER-GARDEN,
IS WITH THE
SINCEREST RESPECT
INSCRIBED BY
WILLIAM CURTIS.

Title-page and dedication from The Botanical Magazine, *Vol.* I, 1787.

House, Piccadilly. Her Grace is beginning to be very botanical.'

Fourteen volumes were issued during the first period of the history of the *Magazine*, which extends to the founder's death in 1799. They contain 504 plates drawn by Sydenham Edwards. Edwards continued to illustrate the *Magazine* after Curtis's death till he withdrew in 1815. By that time he had produced nearly 1,770 drawings. Curtis's colourist was William Graves, and his rendering of the delicate graduation of colours in flowers is often charming. Many of his colours have stood the test of time very well, but some of the whites and heavy reds have faded. The plants illustrated and described are mostly hardy European and North American, together with *Erica*, *Pelargonium*, *Mesembryanthemum* and *Gladiolus* from South Africa. It should be remembered that in 1772 William Masson had been sent out from Kew to the Cape and had thence introduced a large number of plants.

The first plate gives an attractive figure of *Iris persica*. The description is short, and includes the following sentences: 'Its beauty, early appearance, and fragrant blossoms, make it highly esteemed by all lovers of flowers; like the Hyacinth or Narcissus it will grow within doors in a water-glass, but stronger in a small pot of sand, or sandy loam; a few flowers scent a whole apartment; it will also blossom in the open air, but requires warmth and shelter.' Curtis takes pains with his phrases, and his prim, smoothly-rounded style is distinctly pleasing. 'This charming shrub,' he writes of *Coronilla glauca* (t.13), 'which is almost perpetually in blossom, and admirably adapted for nosegays, is a native of the South of France, and a constant

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ornament of our green-houses.' 'There is an elegance in the Jasmine,' he says of *Jasminum officinale* (t.31), 'which, added to its fragrance, renders it an object of universal admiration.' 'The blossoms' (of *Camellia japonica* (t.42)), 'are of a firm texture, but apt to fall off long before they have lost their brilliancy; it therefore is a practice with some to stick such deciduous blossoms on some fresh bud, where they continue to look well for a considerable time.' *Colutea arborescens* (t.81) 'produces a profusion of bloom from June to August, when its inflated pods please from the singularity of their appearance.'

Volume V, 1791, includes the figure of *Sophora tetraptera*, discovered by Sir Joseph Banks in New Zealand and planted by Mr Forsyth about 1774 in the Apothecaries' Garden at Chelsea, 'now extending' (28th April, 1791) 'to a great breadth on a wall with a West aspect, thickly covered with large pendulous branches of yellow flowers (of peculiar richness).'

Among other notable items in this first series may be mentioned *Pelargonium tricolor* (t.240), here first described (Vol. VIII, 1794); *Metrosideros citrina* (t.260, *Callistemon lanceolatus*), the forerunner of many brilliant Australian shrubs, believed by Curtis to be the first that had flowered in England; *Rosa semperflorens* (t.284), which he regarded as one of the most desirable ornamental plants ever introduced into England, actually a variety of *Rindica*—both these in Vol. VIII, 1794; and *Cineraria cruenta* (t.406) from the Canary Isles, the parent of the great variety of florists' cinerarias (Vol. XII, 1798). A beautiful plate is that of *Erica ciliaris* (t.484), a native of Spain and Portugal (Vol. XIV, 1800).

In 1788, the Linnean Society was founded, with Dr Goodenough as Treasurer. Curtis's signature appears third on the Roll Book. During the following year, Curtis moved his plants to a new Botanic Garden at Brompton. He had been greatly troubled, he says, at Lambeth Marsh by the smoke of London, the obscurity of the situation, and the badness of the roads leading to it, as well as 'with the effluvia of surrounding ditches, at times highly offensive.' The new garden occupied about three-and-a-half acres and included greenhouses and a library. A subscription catalogue of the Brompton Botanic Garden was issued in 1792–93. The garden was carefully planned and divided into various quarters: medicinal, agricultural, foreign grasses, British grasses, British trees and shrubs, and so on. Surrounding these were 'all the foreign trees and shrubs, which are able to be naturalized in our climate, and which beautifully decorate, shade and screen the whole.'

A pamphlet issued by Curtis in 1792 contained proposals for a course of herbarizing excursions during the summer months in Battersea meadows. The fee for the course was two guineas. Dr Thornton, who went botanizing with him, says 'His eye was truly microscopic . . . when herbarizing with a large party his keen sight always collected twenty times as many different plants as were obtained by the whole company.'

In 1799, Curtis published a pamphlet on the cultivation of seakale for the use of the table. With each pamphlet he sold a box of seed in his desire to bring the plant into common cultivation. His attention had been called to it by his friend, Dr Lettsom, who had found it eaten by fishermen near Southampton.

Dr Thornton and Dr Goodenough both left descriptions of their friend. He was short and thick-set, ruddy in face, and abounding in good humour. 'I have no pretensions,' he said of himself 'to be considered as a man of letters, or of great mental powers, I know myself and my imperfections. A consciousness of my inabilities makes me diffident, and produces in me a shyness, which some have been ready to construe into pride.'

On 7th July, 1799, Curtis died suddenly of heart failure, and was buried in Battersea (old) Churchyard, opposite the West entrance. The following inscription was placed on the tombstone:

'Here are deposited the remains of Mr William Curtis, Author of the *Flora Londinensis*, and the *Botanical Magazine*, and other works highly serviceable to his country, and honourable to himself.

He died July 7th, 1799, aged 53 years.

"While living herbs shall spring, profusely wild,
Or garden cherish all that's sweet and gay;
So long thy works shall praise, dear Nature's child,
So long thy memory suffer no decay."'

The inscription has become entirely defaced, but it is hoped to renovate it in time for a memorial service in Battersea Parish Church on the Sunday nearest to 11th January, 1946 (i.e. Sunday, 13th January).

The latest biography of William Curtis was published in 1941 by Mr W. Hugh Curtis, Curator of the Curtis Museum, Alton. Mr Hugh Curtis has been able to make good use of a number of letters hitherto unpublished, and his comprehensive work will long remain the standard biography. I have freely drawn upon it in this brief account.

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Electric lighting by luminescence

C. C. PATERSON

Electric lamps of the familiar filament type possess various shortcomings, but it seems unlikely that they are susceptible of much further improvement. Interest therefore centres on the modern method of electric lighting by luminescence, which promises to effect an even greater revolution in illumination than did the introduction of the metal filament lamp some thirty years ago. Dr Paterson here describes and explains some of the main phenomena involved.

INTRODUCTION

The chief technical advance in electric lighting during the past twenty-five years has a dual origin. The first is the property possessed by electric discharges through certain vapours to radiate relatively large proportions of their energy in the visible or ultra-violet regions of the spectrum. The second is the property possessed by certain luminescent materials to fluoresce very strongly when in contact with the discharge.

The luminous efficiencies of temperature radiators have probably reached their practical limit in the gas-filled tungsten filament lamp, and only minor improvements in such light sources can be expected. It will be informative to examine the factors which encouraged the belief that at least equally efficient lamps of other types could be produced.

These factors can be made clear by a study of the diagram (figure 1) showing the distribution of spectral energy in the radiation from a hot tungsten filament, and in that from an electric discharge through low pressure mercury vapour. It will be seen that the radiation from the tungsten filament is continuous and that the peak of the emission occurs in the infra-red or heat region; furthermore, very little ultra-violet radiation is emitted. The proportion of energy emitted in the visible region depends on the temperature of the filament, but at temperatures giving a reasonable life only about 10 per cent. of the input energy appears as light, corresponding to a luminous efficiency of approximately 15 to 20 lumens per watt.

The spectral energy curve of the mercury vapour discharge shows that the radiation is no longer continuous but occurs as narrow spectral lines; a high proportion (some 50 per cent.) of the input energy is emitted in the invisible ultra-violet at a wavelength of 2537 A. In spite of the virtual absence of invisible infra-red radiation from the spectrum of the mercury discharge, its efficiency in lumens per watt is even poorer than that of a filament lamp. The important factor is, however, that the ultra-violet energy of the mercury discharge can be converted into visible radiation by means of luminescent materials, resulting in sources giving white light at efficiencies as high as 60 lumens per watt. It is with such sources that the present article is primarily concerned.

LUMINESCENT MATERIALS AND THE MECHANISM OF LUMINESCENCE

Luminescent materials include fluorescent and phosphorescent substances, the latter being characterized by a continuance of the glow for a time after the stimulation has stopped. These luminescent substances may be regarded as frequency changers of electro-magnetic waves. The change is always from short to longer wave-lengths, and there are, unfortunately, no equivalent conditions or materials which enable the longer wave infra-red heat radiation to be converted into the shorter wave visible radiation. It is for this reason that luminescent materials cannot be used to improve the efficiency of tungsten filament lamps.

Many substances are luminescent to some degree. Mineral oils, some organic substances such as anthracene and quinine, and certain dyestuffs are strongly fluorescent; certain minerals, of which the best known are perhaps willemite, or zinc orthosilicate, and fluorite, or calcium fluoride, also show strong luminescence. Figures 2 to 4 show reproductions from actual colour photographs of some of these substances stimulated by radiation of wavelength 3650 A.

Apart from their use in conjunction with black glass lamps to obtain certain spectacular effects, these materials have no serious application in artificial lighting. Naturally occurring inorganic luminescent materials are too rare, and are in any case too inefficient, to have any practical

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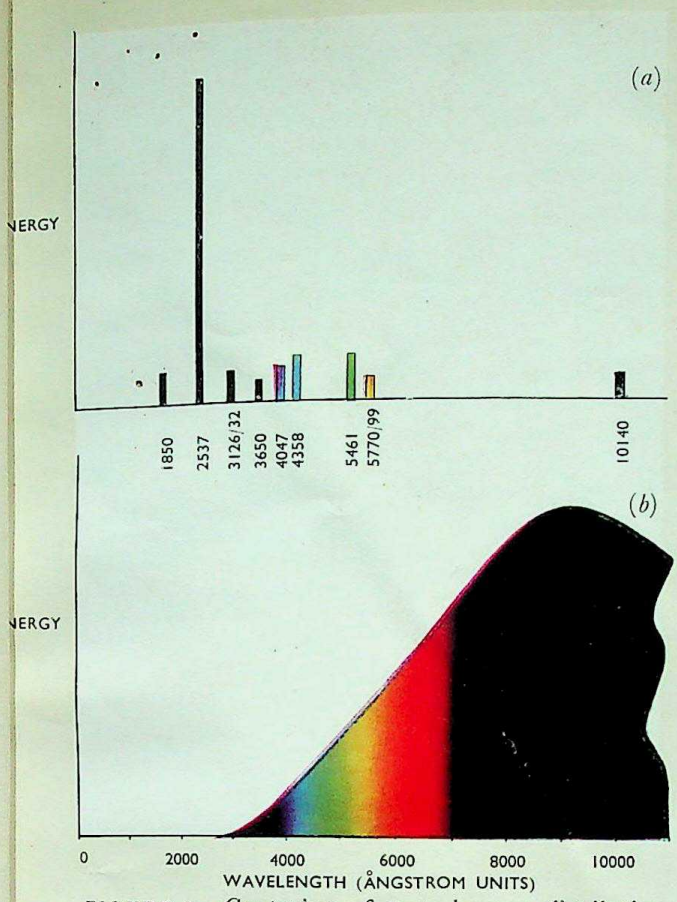

FIGURE 1 – *Comparison of spectral energy distribution of the radiation emitted by an electric discharge and an incandescent tungsten filament. (a) Low pressure mercury vapour discharge. (b) Incandescent tungsten filament.*

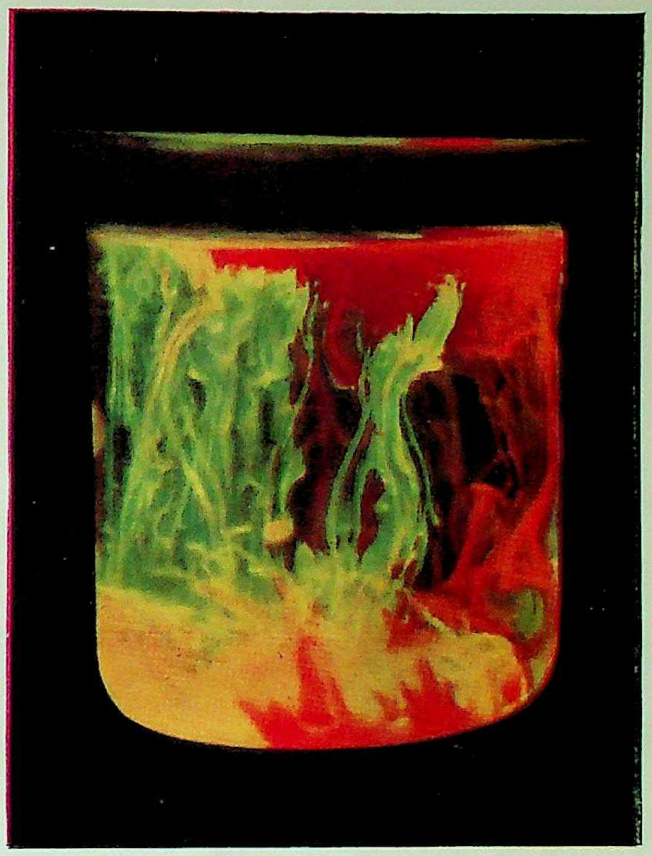

FIGURE 2 – *Luminescent streamers produced by dusting fluorescent dyes (fluorescein and rhodamine) into water irradiated by 3650 A radiation.*

value. The luminescent salts used in discharge lamps are therefore synthesized in the laboratory, either by conventional precipitation methods or by direct union of the dry acidic and basic constituents at a high temperature. In each method exceedingly high purity is necessary, and the material must be fired in special furnaces at temperatures as high as 1,200° C to develop the essential crystalline structure. Before firing, the material is treated with a small quantity of a metallic activator—very often manganese. A range of fluorescent colours is obtained by using different parent compounds or matrices, and sometimes different activators. Table I gives a list of some of the more important luminescent compounds. Figure 5 shows a reproduction in colour of some of these materials stimulated by ultraviolet radiation.

TABLE I

LIST OF MAIN LUMINESCENT POWDERS

Matrix	*Activator*	*Fluorescent Colour*	*Exciting Wavelength*
ZnS	Ag	Blue	3650 A
ZnS	Cu	Green	3650 A
(Zn,Cd)S ..	Cu	Yellow-red	3650 A
Zn_2SiO_4 ..	Mn	Green	2537 A
$(Zn,Be)_2SiO_4$	Mn	Yellow-red	2537 A
CdB_2O_4 ..	Mn	Red	2537 A
$MgWO_4$ ..	Self-activated	Blue	2537 A

The mechanism of luminescence is exceedingly complex, and has as yet been explained only in qualitative terms. Very briefly, modern theory assumes that the activating atoms form so-called active centres in the crystalline matrix, in which the atoms of the activator are more or less isolated

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FIGURE 3 – *Artificial silk dyed with various fluorescent dyes and excited by 3650 A radiation. In the powder form these dyes are not luminescent but become so when dispersed in a suitable solvent or fabric.*

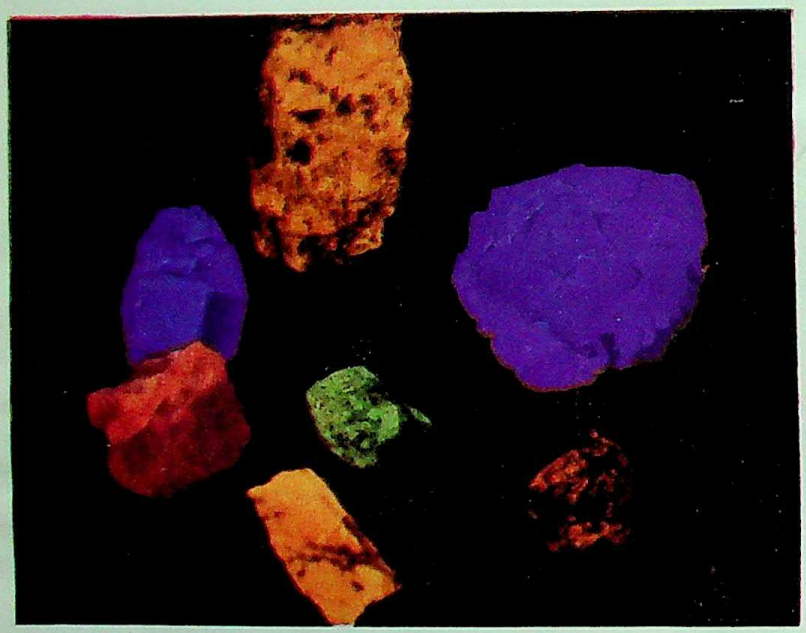

FIGURE 4 – *Luminescent minerals under 3650 A radiation. Luminescence in natural substances is not, as a rule, very well developed. The minerals shown here are exceptional in that they exhibit marked luminescent effects.*

FIGURE 7 – *Picture painted with luminescent sulphides viewed in normal light. The drab appearance is due to the lack of natural colour in the luminescent pigments.*

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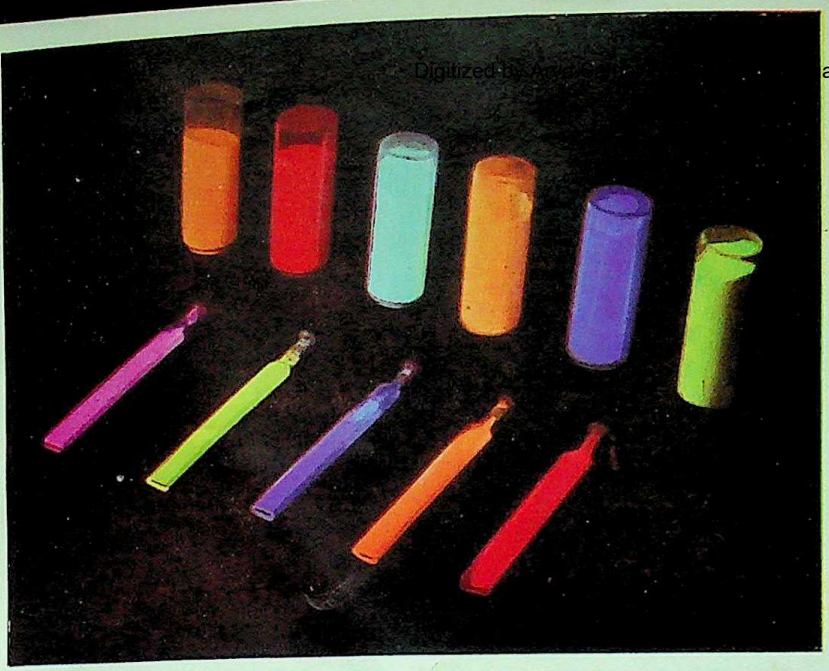

FIGURE 5 – *Synthetic luminescent powders excited by long-wave ultra-violet radiation. The powders are mainly zinc and zinc-cadmium sulphides activated by silver and copper.*

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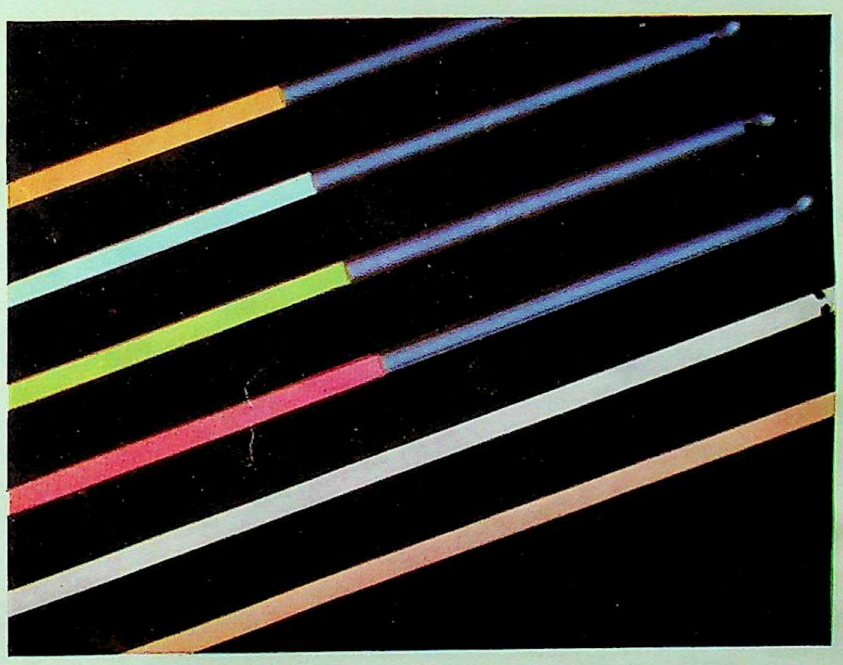

FIGURE 6 – *Fluorescent lamps coated with various fluorescent powders. Some of the tubes have been left uncoated over half their length to show the colour of the unmodified discharge. The bottom two lamps have been coated with blends of powders to give daylight and warm white effects.*

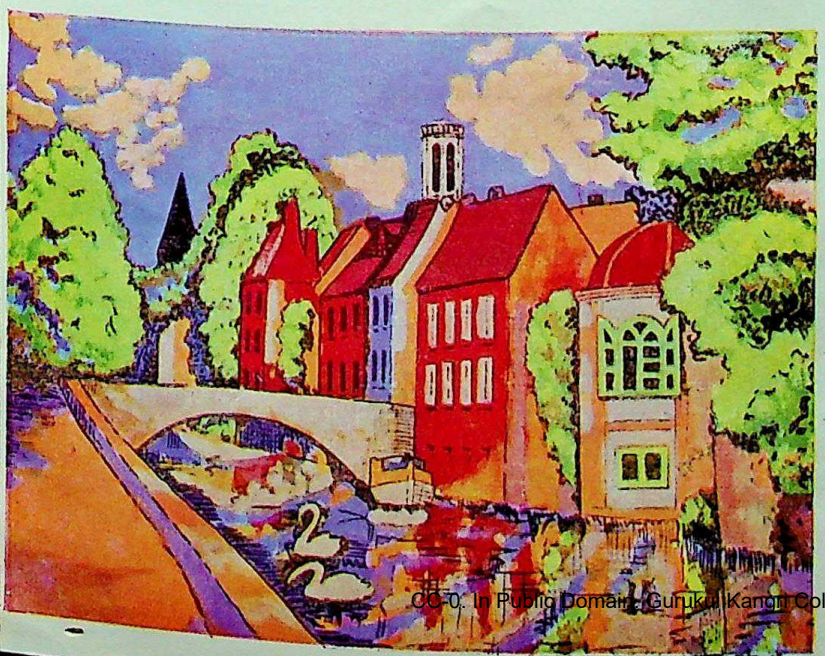

FIGURE 8 – *The same picture irradiated by long-wave ultra-violet radiation.*

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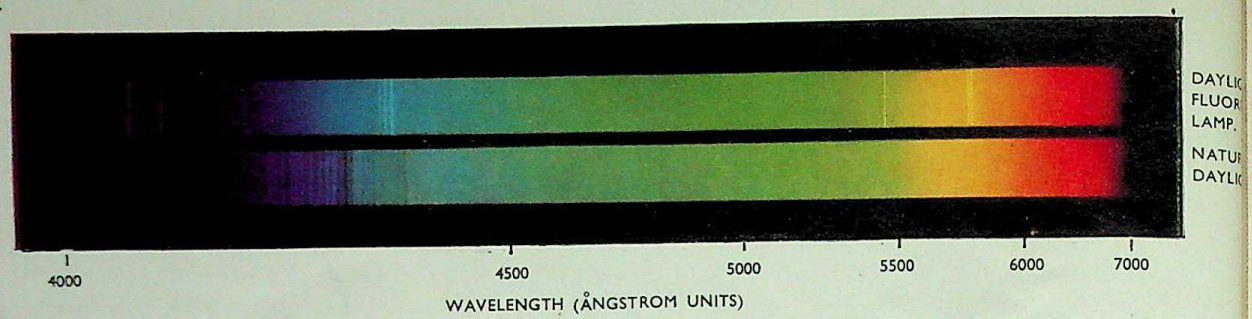

FIGURE 9 – *Spectrum of daylight fluorescent lamp compared with that of natural daylight. Mercury lines superposed on the continuous background will be noted in the former spectrum. The Fraunhofer absorption lines in the daylight spectrum can also be seen.*

from their fellows by the molecules of the crystalline lattice. This enables them to absorb and emit energy by transition of electrons between energy levels which are, however, associated also with the molecular arrangements in the crystal. Thus, instead of fine spectral lines resulting from transitions between discrete energy levels, as in electric discharges, the energy levels give rise to radiation covering a range of wavelengths.

LUMINESCENT EFFECTS WITH BLACK GLASS LAMPS

Apart from their use in discharge lamps, with which the present article is primarily concerned, certain luminescent powders have come into use for providing spectacular lighting and display effects in conjunction with black glass lamps. Figure 8 shows a picture painted with sulphide phosphors viewed under black lamp radiation, while figure 7 shows the same picture under ordinary white light.

It is interesting to note that with normal paints and pigments subtractive mixtures of light are obtained. Thus a yellow pigment is yellow because it absorbs blue and, as everyone knows, a mixture of blue and yellow paints gives green. In mixing luminescent pigments however, the artist has to deal with an additive mixture of lights, and blue and yellow luminescent materials do not give green when mixed, but white. It is, of course, necessary for the artist to mix his luminescent pigments and to use them under ultra-violet radiation with visible light excluded as far as possible. With a little practice the new technique is easily acquired.

It has often been proposed to use, as sources of illumination, large areas such as walls and ceilings coated with luminescent materials and irradiated by black glass lamps. This form of illumination has interesting possibilities for decorative purposes, but is hardly likely to come into use for general lighting because of its high cost and low luminous efficiency, the latter amounting to only one or two lumens per watt.

THE LUMINESCENT COATING

In practical fluorescent lamps the luminescent material is applied, usually suspended in a suitable organic binder, as a thin uniform coating to the inside surface of the tubular envelope. The binder is removed by heat during the processing of the lamp; this leaves the powder layer exposed to the direct action of the ultra-violet radiation emitted by the discharge. Owing to the need for keeping the pressure of the mercury vapour low, in order to secure the maximum output of ultra-violet radiation, fluorescent tubular lamps operate not much above normal ambient temperatures, and for this reason are generally large in relation to their consumption of power.

Figure 6 shows a number of fluorescent lamps 5 feet long and $1\frac{1}{2}$ inches in diameter, each rated at 80 watts. Some of these lamps have been coated with various luminescent powders over half their lengths only, the other half being left uncoated to show the mercury discharge. It will be seen that the fluorescent coating glows so brightly that the light from the mercury vapour itself is almost completely masked by the resulting luminescent glow.

To obtain white colours of spectral energy distribution approximating to that of the sun, it is usual to employ coatings comprising mixtures of individual powders. Two such white lamps are shown at the bottom of figure 6. It is interesting to record that recent developments in this country have resulted in single luminescent compounds which give, by themselves, satisfactory white

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colours. The similarity between the spectrum of a daylight fluorescent lamp and that of natural daylight is shown in figure 9. The line radiation in the former spectrum corresponds to only about 10 per cent. of the total visible radiation, and does not appreciably distort the colour rendering of the light.

THE QUANTUM EFFICIENCY OF LUMINESCENT MATERIALS

In considering the possibility of future developments it is important to estimate what percentage of the theoretical maximum of efficiency is achieved by modern luminescent powders. A luminescent substance is said to be 100 per cent. efficient if it emits one quantum of radiation for each quantum absorbed; but it must be remembered that, since the energy in a quantum of radiation is inversely proportional to the wavelength, there is an inevitable loss of energy in transforming ultra-violet radiation into white light. This amounts to approximately 50 per cent. for ultra-violet radiation of wavelength 2537 A.

The quantum efficiency of a powder depends on the method of preparation, and on the precautions taken with regard to purity and related factors. It is obvious, for instance, that a luminescent powder having considerable body colour is likely to have a lower quantum efficiency than a similar powder free from body colour. Quantum efficiencies can be determined from the measured luminous efficiency of fluorescent lamps of known spectral energy distribution dissipating a known amount of ultra-violet energy: values as high as 85 to 90 per cent. are usual. It will be seen, therefore, that further considerable improvements in the efficiency of fluorescent lamps by improvements in the quantum efficiency of the powders can hardly be expected.

LUMEN MAINTENANCE OF FLUORESCENT LAMPS

The above remarks refer to powders in their initial state before the lamp has been in operation for any appreciable time, and it is not to be inferred that no further improvement in the powder is possible. One of the less desirable characteristics of mercury-filled fluorescent lamps is the fall in light output as the lamp is run; this is due to the formation of deposits of mercury and mercury compounds on the fluorescent coating under the action of the discharge. The slow disintegration by the discharge of the material of the filament, part of which deposits on the coating, is also a contributory factor. The film so formed absorbs some of the ultra-violet radiation, and thus, of course, reduces the efficiency of the lamp. The fall is most rapid during the early part of the life of the lamp and thereafter proceeds more slowly. It depends to some extent on the current density: with lamps of fairly high current density, such as the British 80 watt lamp, it may amount to 20 per cent. during the first few hundred hours and a further 20 to 30 per cent. during the subsequent 3,000 hours.

A number of factors influence the rate at which the absorbing film on the coating is formed; among them may be mentioned the nature of the luminescent material itself. This aspect of powders is receiving close study, and it is from this point of view that the greatest improvements in luminescent powders are likely to arise.

PRACTICAL FLUORESCENT LAMPS

Table II gives the wattages and dimensions of fluorescent lamps likely to be marketed in Britain within the next year or so. These lamps will be available in a daylight colour and also in a warm white colour for more restful lighting. Both colours are shown in figure 6.

TABLE II

DIMENSIONS AND WATTAGES OF BRITISH FLUORESCENT LAMPS

Nominal Lamp Dimensions		*Lamp Wattage*
Length (feet)	*Diameter (inches)*	
5	1½	80
4	1½	40
3	1	30
2	1½	20
2	1	20
1½	1	15

The average efficiencies and lives of fluorescent lamps are from two to three times those of ordinary tungsten lamps. It may be said, too, that the special characteristics of colour and diffusion possessed by fluorescent lamps, although difficult to measure, rank as high as luminous efficiency in importance to the illuminating engineer, and to the numerous users who show aesthetic discrimination. Fluorescent lamps are already well established for industrial and commercial lighting.

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Some aspects of dairy bacteriology

A. T. R. MATTICK

Dairy bacteriology is a comparatively young branch of applied science, but it is rapidly growing in importance and already has much success to its credit. Its main concern is with milk itself, a foodstuff with a unique role in human nutrition, but one which unfortunately is too often contaminated by harmful bacteria. To ensure the supply of dietetically safe milk is not, however, the dairy bacteriologist's only aim, and the present article describes various other aspects of modern work, much of which has notable scientific interest.

Cow's milk plays a unique role in the diet of most civilized peoples. The cow converts vegetable products in large quantities into first-class protein, fat, and carbohydrate, and blends them in water with the necessary inorganic salts and vitamins in such a way that milk is almost a complete food. Milk is also an admirable medium for the growth and survival of many kinds of bacteria, and the bacteriology of milk and its products is a rich field for investigation. It is not possible here to deal with more than certain aspects of the subject. Microbiologists, as recent publications show, are beginning to appreciate the importance of the study of the effect of physical factors and environment upon the constitution and metabolism of micro-organisms. In a mixed population of bacteria many factors, not least the growth products, among which are antibiotic substances, determine the predominance of types, and it is proposed to give some account of their interactions.

PASTEURIZATION

Although great technical advances, actual and potential, have been made in the preparation of dried and otherwise preserved milk, it is likely that the demand of the public for fresh liquid milk will continue to expand in spite of the strength of the argument that, as milk contains some 87 per cent. of water, it is uneconomical to transport and distribute it in its natural form. For hygienic reasons, the fact that milk is so distributed imposes heavy responsibilities on the producer and seller of milk.

If all the micro-organisms which may be present in milk were non-pathogenic to man and animals, the spoilage which they cause might be accepted as merely inconvenient and wasteful. But this is not so, since cows themselves suffer from bacterial diseases such as tuberculosis, contagious abortion, streptococcal and staphylococcal mastitis, and even *Salmonella*-enteritis, all of which are communicable to man. The only safe, satisfactory, and economical method of killing these organisms is by pasteurization, which makes use of the fact that if maintained at temperatures in the region of 60° C for approximately 10 to 15 minutes, or an equivalent combination of temperature and time, the vital protoplasm of vegetative bacteria is denatured and the organisms are killed. The numbers of animals suffering from the more serious of these diseases in a dangerous form may be relatively small, but when the milk of several herds is mixed the dangers of infecting large numbers of consumers are patent.

It is, of course, possible—though difficult—to produce milk which is free from organisms causing some of these animal diseases, but the chance is always present that the milk may be subsequently infected with a variety of organisms from human sources.

The elimination of pathogenic organisms is accepted as the main reason for pasteurization, but at the same time most of those causing souring and other faults are destroyed as well. The microbial life of the milk has to start afresh after pasteurization, so that it is possible to provide city dwellers with unsoured milk—a virtual impossibility with raw milk when the 'milk-shed' is at a distance from the centre of distribution.

THE AËROBIC SPORE-FORMERS

The process of pasteurization itself provides many interesting problems in bacteriology. Ordinary raw market milk may contain considerable numbers of organisms in great variety, but in practice the greater part of the flora is confined to comparatively few types: 'lactic' and other streptococci, coliform organisms, micrococci, and some spore-forming types. The latter are probably ultimately derived from the soil. Farm and factory utensils and apparatus are normally sterilized by steam, which, properly applied, kills all

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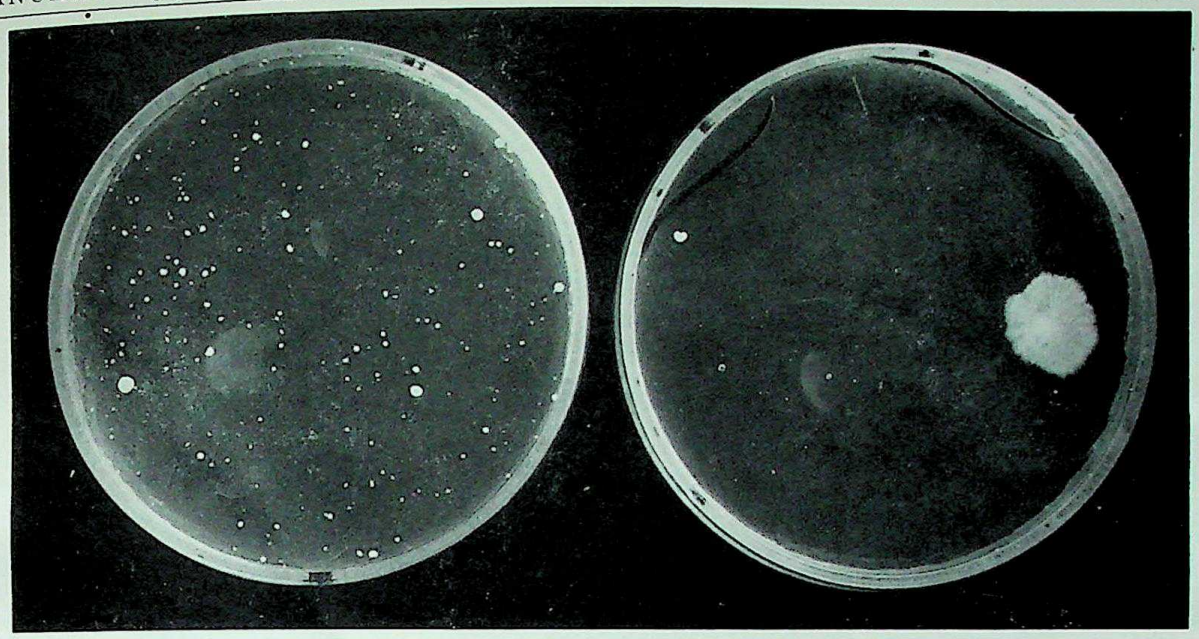

FIGURE 1

(*a*) *Agar plate containing dried milk. Screened from light. Two-hundred-and-forty-seven colonies have grown.*

(*b*) *Agar plate as in (a) but exposed to light on a sunless day. Two colonies have grown.*

vegetative organisms but fails to kill the spores of the aërobic spore-forming types, which are very resistant to heat. Many of these are proteolytic rather than acid-forming, and because of the unsuitability of the *p*H produced in the reaction, are unable to compete with the lactic streptococci; they therefore cause no trouble in ordinary market milk. When, however, the milk is taken from the cows with good hygienic precautions to avoid contamination, or when the flora has been reduced by pasteurization, which does not kill spores, serious difficulty may arise from spore-formers. It was first observed at Reading, and has recently been confirmed in other laboratories, that many spores will not germinate unless some stimulus, such as, for example, the sub-lethal heat of pasteurization, is applied. Germination is then rapid, and, in the absence of competition from acid-formers, spore-forming types become predominant.

Many produce a clotting enzyme, similar to rennet, which causes the milk to gel without souring. With some types the cream on the milk, which provides the necessary highly aërobic conditions, becomes 'broken' into aggregates, possibly because the proteins adsorbed on the fat globules are disturbed by the products of bacterial metabolism. In 'sterilized' milk, in containers allowing the admission of sufficient oxygen to permit germination of the spores which have received the necessary stimulus and have survived the severe heating process, some sporing bacteria form free phenols and cresols from the tyrosine of the milk protein. Sometimes so much is formed that the milk is made unusable and the unfortunate seller is liable to be accused of fraudulent additions.

From spore-formers of several types, 'vegetable' rennets have been produced and successfully used in making cheese for communities which object to animal rennet.

The aërobic spore-formers (genus: *Bacillus*) are an interesting group but have yet to be studied intensively. They have already yielded some powerful antibiotic substances, including gramicidin. All dairy bacteriologists must have observed zones of complete inhibition of other organisms in the neighbourhood of colonies of spore-formers growing on agar plates inoculated with milk. The effect is often so marked when making agar-plate counts of dried milk as to render impossible by this method anything approaching an exact enumeration.

THERMOPHILIC BACTERIA

The members of the genus *Bacillus* grow under the most diverse conditions and are very adaptable.

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FIGURE 2 – *Inhibition of growth of the tubercle bacillus. The bottles (photographed flat) contain a liquid medium inoculated on the surface with a human strain of tubercle bacillus.*
(*Left*) *Control: no added antibiotic.*
(*Centre*) *Added antibiotic: some inhibition.*
(*Right*) *Added antibiotic, greater concentration: complete inhibition (the original inoculum has not grown).*

The so-called *thermophils* may cause serious difficulty in large scale pasteurization. In this process economy in heat is achieved by using the outgoing hot milk at 63° C to warm the incoming cold milk in a heat-exchanger. The temperature is normally about 54° C, and under these conditions thermophils, both non-sporing streptococci and aërobic spore-formers, may grow rapidly. The latter may also cause serious trouble in still hotter parts of the plant. A heavy infection of organisms of this type can be eradicated only by the most meticulous cleansing with detergents, and disinfection with suitable chemical disinfectants; steam is quite ineffective. The spore-forming thermophils grow freely at temperatures far above those necessary to destroy ordinary vegetative types of bacteria. Fundamentally they are very interesting and important, since their cell contents continue to perform their vital functions under apparently impossible conditions. Their composition and general make-up must therefore differ essentially from those of ordinary bacteria. It has, indeed, been found that their 'generation time' is significantly shorter than that of other organisms. In a static culture the various phases—lag phase, logarithmic-growth phase, and the phase of decline and death—are completed in a short time. Perhaps this is an attempt of living organisms, growing at temperatures much higher than usual, to conform to van't Hoff's equation for the speed of a *chemical* reaction in relation to temperature. The phenomenon of growth at such high temperatures is all the more remarkable because the vegetative cells are killed when the temperature rises slightly above the maximum for growth. In cultures on agar plates, spore-forming thermophils from milk are abnormally sensitive to light. After passing through a plate-glass window, the Petri-dish lid, and the agar in which the organisms are embedded, weak daylight in March causes, after short exposures, a sharp reduction in the numbers which grow on subsequent incubation. Longer exposure may completely sterilize the plates. Plate cultures of dried milk (figure 1) also show that other organisms which have survived severe heating are very vulnerable to the effects of light. The exact mechanism of this reaction is not known. It may be photodynamic, through the pigment of the organism itself or of the medium, or may be due to traces of hydrogen

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peroxide, to which such organisms may be expected to be more than usually sensitive.

HEAT RESISTANCE

The general question of the resistance of bacteria to destruction by heat is constantly before the milk bacteriologist. Milk as it comes from the udder of a healthy cow contains only micrococci and corynebacteria, either together or alone, in very small numbers, and these have no great heat resistance. Such milk is sterilized by pasteurization. Usually, however, milk from the udder contains a more mixed flora consisting of streptococci, staphylococci, micrococci, and corynebacteria. These, together with a small number of other organisms picked up in the course of milking, constitute the flora, numerically small, of well-produced raw milk. All of them except the corynebacteria (of a type different from those found in *aseptically* taken milk) are easily destroyed by heat. But in ordinary milk, taken from large bulks handled in the usual way, it is common to find streptococci and micrococci of which considerable numbers survive pasteurization. These organisms have acquired heat resistance during their sojourn on imperfectly cleaned and sterilized surfaces, and their resistance appears to be related to their immediate previous history. It is true that some vegetative organisms found in milk, e.g. coliform types, are able, in small numbers, to survive pasteurization, but permanent heat resistance of this type is not common and is apparently confined to a few cells in the population. There are nevertheless some vegetative organisms like the saprophytic *Microbacterium* (*Corynebacterium*), common on dirty apparatus, which can survive heating in milk to about 90° C for 10 minutes.

THE LACTIC ACID BACTERIA

Organisms of many different species cause faults in milk or dairy products, but those fermenting lactose, with lactic acid as the main end-product, are the most important for several reasons. The so-called 'lactic' streptococci, *Str. lactis* and *Str. cremoris*, are the main cause of the souring of milk at normal temperatures. They have recently been shown to belong to a distinct serological group of the genus *Streptococcus*, producing antibodies of a type which do not react with the antigens of other streptococci. They have at last been clearly differentiated from *Str. faecalis*, a common component of the flora of the gut of many animals, of which they were considered by some to be mere varieties. In milk their growth is so rapid that they usually predominate in the flora. Lactic acid is produced by the fermentation of lactose until the concentration reaches about 1 per cent. Small quantities of by-products, such as acetic and propionic acids, and acetyl-methyl-carbinol and its oxidation product diacetyl (an 'aroma' compound), are also formed. If, however, growth is slow, as at lower temperatures or in the comparatively adverse conditions of some of the milk products, the degradation of lactose to lactic acid is incomplete, and the intermediate compounds form a greater proportion of the products of fermentation. When the fermentation ceases with a lactic acid concentration of about 1 per cent., the milk attains a certain security from attack by organisms which would grow freely in it at the normal *p*H of about 6·6. In particular it is kept free from those which attack the proteins with the production of unpleasantly-tasting compounds such as peptones.

BACTERIA IN CHEESEMAKING

Without the lactic acid bacteria there would be no cheese. Cultures of lactic acid streptococci ('starter') are added to the milk and encouraged to grow rapidly by raising the temperature to about 28° C. This has the dual effect of suppressing the growth of undesirable organisms and of bringing the milk from its normal *p*H to that most favourable for the action of the clotting enzyme, rennet. Unless the physical condition of the resulting curd is thus made correct, the texture of the cheese will not be homogeneous; nor will it be sufficiently anaërobic, after moulding, to inhibit the growth of those organisms which attack the proteins. Within about three days of making, the lactose in the curd is exhausted and the growth of the streptococci ceases, although some continue to survive for long periods. Under the anaërobic conditions induced by pressure and the contraction of the curd, lactobacilli, present in small numbers in milk, begin to grow. This they do by virtue of their ability to grow at a low *p*H and in the presence of a considerable salt concentration, a property fortunately not possessed by most other bacteria. As ripening proceeds, under the influence of the rennet enzymes and the lactobacilli, the *p*H of the cheese rises from about 5 to 5·4.

If the original starter fails to produce the necessary acidity the quality of the cheese will be poor and it may be inedible. Milk usually contains small numbers of organisms of the genus

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Clostridium. These are anaërobes, and the proteolytic types break down the protein molecules with the production of hydrogen sulphide and evil-smelling mercaptans. They are unable to grow in well-made cheese because of the low *p*H, but if the starter fails to produce the necessary acidity and if, by chance, the inoculum of anaërobic organisms is at all substantial, a very unpleasant mass, aptly called 'Dead Man's Finger,' will result.

BACTERIOPHAGE

Failure of the 'starter' streptococci may result from several causes. The most disastrous of these is attack by bacteriophage. Since its discovery in 1915, bacteriophage has been intensively studied, but its origin and nature are still in doubt. It appears to be a virus-like entity which penetrates the surface antigens of *actively growing* bacterial cells and brings about their disintegration and death. Bacteriophage is highly, but not absolutely, specific for bacterial types or even strains, and advantage has been taken of this property to trace the origin of, for example, staphylococci infecting a population. 'Starter' in cheese factories is usually made in bulk. If this becomes infected with phage particles which are disseminated into the air in the mist from whey separators, or which are air-borne from the cheese vats or factory sewage, the streptococci may be killed and the starter made useless for the production of acid in the milk. Alternatively, residues of whey from a vat of milk in which the phage concentration has been insufficient to prevent the development of the minimum necessary acidity may form an inoculum of such a concentration that acid development may be inhibited in milk subsequently put into the vat.

Owing to the considerable type or strain specificity, if the phage type of the starter streptococci is known, the existing culture may be replaced by another of a different phage type, and the trouble abolished. The relief is, however, likely to be only temporary, and constant vigilance is necessary. Most cultures, after attack by phage, will resume growth later, owing to the presence of certain cells which are resistant to penetration by the phage particles; but they are often, for other reasons, unsuitable as starters. It has been necessary to institute a rigid bacteriological technique in the preparation and protection of cheese starters.

ANTIBIOTIC SUBSTANCES

Bacteriophage is not the sole cause of difficulty with starter growth. If dairy utensils, e.g. milking machines, are not regularly cleansed, a flora of *Str. lactis* of a peculiar type may be established and the milk thus infected. These streptococci are themselves acid producers, but they also produce a powerful inhibitory substance and prevent the starter organisms from growing, making cheese-making difficult or impossible. As little as 3 per cent. of milk in which the inhibitory organisms have grown will prevent growth of the starter in the cheese vat. The inhibitory substance is now being investigated. It has been found to protect mice from heavy doses of virulent streptococci, and to prevent the growth of many types of streptococci of human and animal origin, *Clostridium*, *Corynebacterium*, and some species of *Bacillus*. Its most interesting property is, however, its power to inhibit *in vitro* human and bovine tubercle bacilli (figure 2). Work is proceeding here at Reading, and with colleagues in other institutions, on the isolation, purification, and testing of the substance and its therapeutic assessment. It is evidently very powerful since the best preparations inhibit the test organisms at a concentration of 6×10^{-6}.

SPARING ACTION

It was first shown here at Reading that the oxidation of vitamin C (ascorbic acid) in milk is strongly catalysed by light. It was also observed that if bacterial growth, particularly that of the harmless acid-forming types, is rapid, this oxidation is strongly opposed and under certain conditions may be prevented from proceeding. Thus it may happen that sour milk which the seller strives to avoid may contain more ascorbic acid in available form than milk with the best keeping quality! Although the quantity of ascorbic acid in average milk is comparatively small, it is a significant proportion of the average intake.

Tinned copper, because of its ease of fabrication and high heat-conductivity, has been largely used for dairy plant and apparatus, particularly milk coolers. Copper is soluble in milk, and even in small quantities acts as an oxygen catalyst and causes the rapid oxidation of the unsaturated fatty-acids of the milk, with the production of the very unpleasantly-tasting compounds in, for example, 'oily milk.' This condition is common in milk containing few bacteria and in cold weather when the growth of bacteria is slow. In warm weather, when the growth of bacteria is rapid, their reducing capacity may be sufficient to prevent the oxidation catalysed by copper. Since bare copper surfaces are potentially dangerous, they should be avoided in milk plant.

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A cycle of fern anatomy

C. W. WARDLAW

It is little more than a century ago that the discovery was made that the growth of the vast majority of plants proceeds from an apical growing point. This discovery threw much light on the development of plants and was of particular value in the study of evolutionary processes. It also prepared the way for an inquiry into the causes underlying the observed forms and structures. Professor Wardlaw here gives an account, with special reference to the ferns, of the development of these two aspects of plant morphology and of the contemporary outlook.

Under the seductive influence of Goethe and the nature philosophers, botanists of the early decades of the nineteenth century were largely preoccupied with speculative problems. As working scientists their studies had largely fallen into abeyance: in many universities the science of plant anatomy and the development of microscopic technique were static or non-existent, despite the magnificent start given by the earlier exponents. This state of affairs continued until Schleiden, little more than a hundred years ago, trenchantly preached a new gospel—that the high road to discovery lay in the study of development. A period of remarkable progress ensued. Von Mohl restored the study of anatomy, while Naegeli, by addressing himself to the questions of how cells—the units of plant construction—are formed in growing vegetative organs, founded and elaborated the theory of cell formation. In particular he showed how far the processes are the same in the lower cryptogams, such as the Algae, and in vascular plants, e.g. ferns and flowering plants. It thus became possible to give a coherent account of the development of tissues and organs from the unicellular zygote, or fertilized egg, to the multicellular adult of complicated form and structure. In Naegeli's view, the history of development was not to be regarded merely as one of various ways of investigating plant form but as identical with the investigation of organic nature. He proceeded from an examination of simple organisms, such as the Algae, to the more complex types of organization seen in ferns and flowering plants. In these studies the initiation of organs and their subsequent development were referred back to cell-formation during growth at apical growing points. These observations were amplified by Wilhelm Hofmeister and others, particularly for the higher cryptogams.

Prompted by the writings of Schleiden, Hofmeister devoted himself to a study of what was then an almost completely unexplored field, namely the reproduction and embryology of Bryophytes (mosses and liverworts) and Pteridophytes (ferns, lycopods, and horsetails), with comparable studies of seed plants. In fact, he worked out what we now describe as the 'life history' of these plants. From his cumulative experience he was able in 1851 to enunciate a generalization of the greatest importance, namely, that mosses, liverworts, the ferns and their allies, gymnosperms, and angiosperms all share a common life-cycle, characterized by the same critical events and phases in development, and by a recurrent alternation of generations. This work, enlarged and published in English in 1862 as the *Higher Cryptogamia*, is a land-mark in the development of botanical science. As an example of Hofmeister's exactitude and careful attention to detail a page of fern anatomy from the *Higher Cryptogamia* is reproduced here (figure 1). He was not without brilliant contemporaries in the same field. Of these, Stenzel deserves particular mention for his studies of the vascular anatomy of ferns, some of his reconstructions being as good as any that have ever been made (figure 2).

Although an endlessly varied and virgin field lay before him, full of treasures and surprises to delight the professed anatomist, Hofmeister's work was not merely descriptive. He was, in fact, highly endowed with the questioning, scientific mind. It was not enough for him to observe that during the development of a particular species a regular succession of characteristic changes in form and structure took place: he constantly inquired, How does the observed form come to be? To what processes of growth can the observed structural developments be related? What internal and external factors determine specific structural organization? The substance of such investigations he described in 1868 as the *General Morphology of Growing Things*. In short, he tried to apply

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mechanico-physical considerations to the explanation of the development of form and structure in plants, and, together with the data of physiological experiments, to derive generalizations therefrom—an attitude which today we should consider to be truly scientific.

It might be thought that, as a result of these admirably objective inquiries, botanical science had at length been established on a broad and sure foundation, one in which morphology and physiology were seen to be inseparable aspects of the same theme. It might further be anticipated that our knowledge of the factors which influence the development of form and structure in plants would now be well advanced. But this is hardly so, and it is therefore relevant to ask the reason. The answer is to be found in another development in biology, contemporary with the causal investigations of Hofmeister. In 1859, Darwin published the *Origin of Species*. In the period that followed the enunciation of the Theory of Descent, the details of plant structure, together with such facts as could be gleaned from the fossil record, were regarded chiefly as providing materials for comparative studies and for the construction of phylogenetic systems; in everyday language, for reconstructing the 'family tree' or 'genealogical table.' There was, in brief, a very marked swing away from the causal outlook which had characterized Hofmeister's later studies. It was no longer a question of: How does the observed form come to be, in terms of nutritional, temporal, spatial, and mechanical factors? but: What family relationship, if any, is indicated by the observed form, and how can this information be applied to trace the course of evolution during descent? The general or causal morphology of Hofmeister was, in fact, displaced by the special or comparative morphology of the students of evolution. Now, it is evident that there can be no study or interpretation of evolution in plants or animals without having recourse to comparative morphology. The evidence of evolution is seen in the changing form and structure of plants during the passage of geological time, and in the diversity of form and structure in living plants. As a result of the studies which were undertaken in the phyletic interest, our knowledge of the range of plant structure was enormously extended. A vast new realm, patently worthy of exploration, must indeed have opened out before the comparative morphologist. In particular, the ferns and their allies, the progenitors of which reach back to the Upper Silurian and Early Devonian Periods, were found, more than any other class of plants, to provide the raw materials for the study of evolution. Plant anatomy, now provided with an integrating thesis of the most far-reaching possibilities and interest, had come into its own again: in particular, apical growing points, the vascular or conducting system, the spore-producing members, and the embryological development, all received close attention. In these studies, in which British botanists took a leading part, the criteria of comparison based on a study of related living organisms were checked against the evidence of the fossil record; and, bit by bit, a coherent if still speculative and necessarily incomplete account of the evolution of land plants was sketched.

Several decades passed before the methods or conclusions of the phyletic morphologists were seriously challenged. But gradually doubts began to accumulate. A bad feature of the phyletic period was that plant morphology and physiology were largely pursued as separate disciplines. Morphologists and anatomists, moreover, tended to resort to facile pseudo-physiological 'explanations' of the functions and adaptive value of tissues and organs. Such assumptions were typically not tested by experiment. Then other difficulties cropped up. Hitherto, similarity of form or structure had been tacitly accepted as an indication of genetic affinity or blood relationship, i.e. related organisms, though subject to specific and generic differences, nevertheless had the same underlying form and structure. But, as the anatomical survey was widened, it was realized that the same structural features might occur in plants which, as judged by all other criteria, were in no way related. In short, it became evident that parallel or *homoplastic* development was of frequent occurrence in the plant kingdom. This led to the view that instead of there having been one main family tree, or one main line of descent, as had generally been assumed by biologists of the Darwinian period, it was probable that there had been many parallel lines of descent from primitive ancestors. The family tree had, in fact, become a thicket. Later, the ultra-cautious and the pessimistic were to hold that it had been reduced to a bundle of sticks; that the 'genealogical table' was 'an. illusory vision' and the search for common ancestors 'a hopeless quest.' Yet another consideration tended to undermine the results of comparative studies. This was a recognition of the fact that the changes in configuration undergone by an organ or tissue, e.g. the vascular system, during development, might be referable, not to

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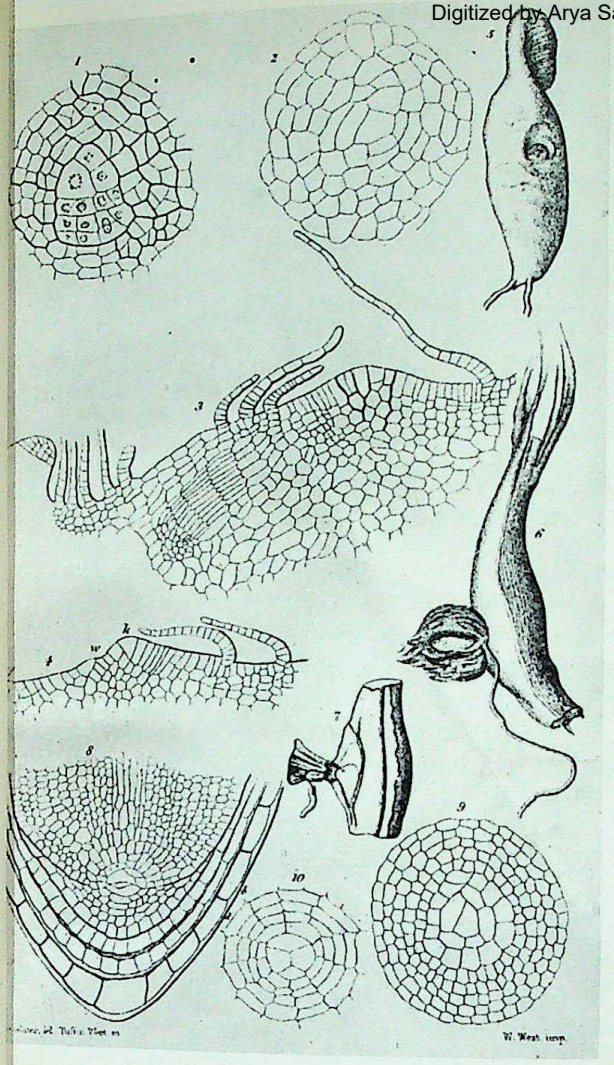

URE 1 – *Reproduction of a plate of fern anatomy from fmeister's* Higher Cryptogamia, 1862; *showing, for the le Fern,* Dryopteris filix-mas: 1, 2, *downward view of the ot apex;* 3, 4, *median longitudinal sections of the shoot apex;* 6, 7, *details of lateral buds;* 8, *longitudinal section of a tip;* 9, 10, *cross-sections of a root tip.*

FIGURE 2 – *Reproduction of a plate of fern anatomy from a memoir by Stenzel,* 1861; *showing shoots, rhizomes, and dissections of the conducting or vascular system of a number of ferns.*

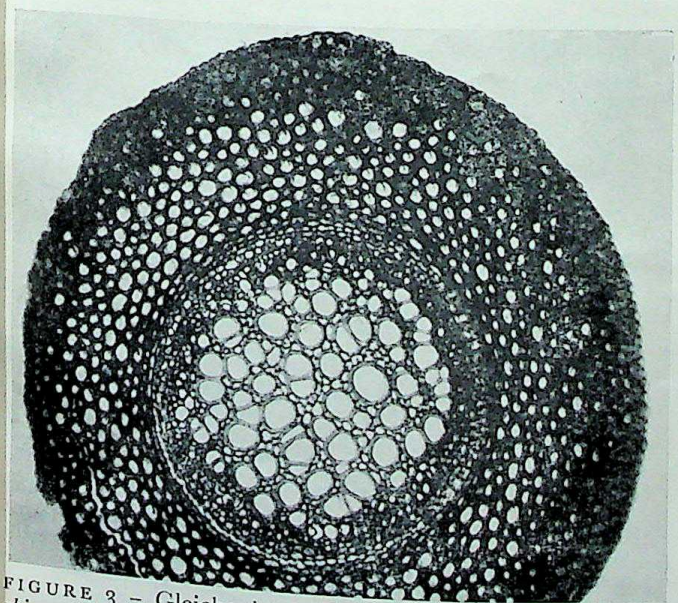

FIGURE 3 – Gleichenia dichotoma. *Transverse section of a rhizome showing the protostelic vascular system.* (× 70.)

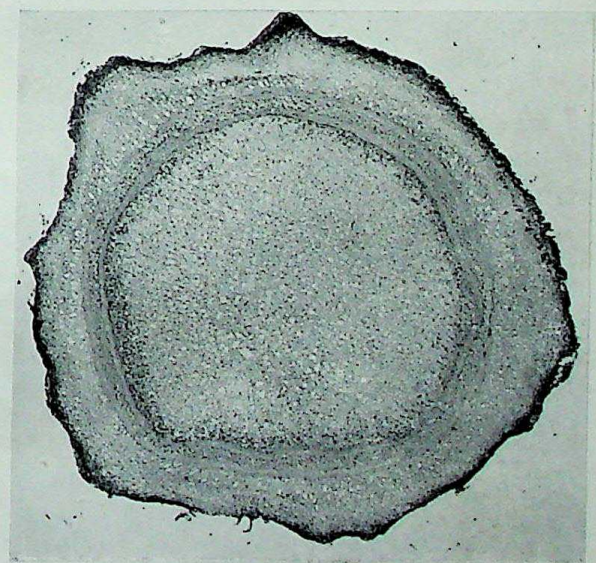

FIGURE 4 – Dryopteris aristata. *Cross-section of a shoot. The solenostelic vascular system has been induced experimentally by the systematic removal of all young leaf primordia.* (× 7.)

(Figures 3 and 4, photographs by E. Ashby.)

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FIGURE 5 – Dryopteris aristata. *Cross-section of the same shoot as Figure 4, but lower down in the normal region, showing a dictyostelic vascular system: the separate vascular strands collectively constitute a meshwork.* (× 5·25.)

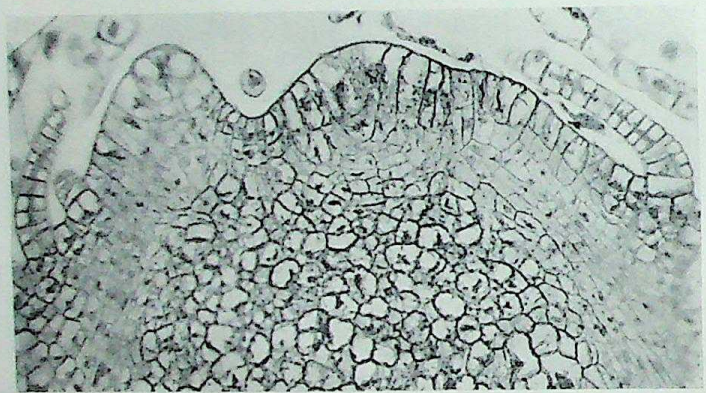

FIGURE 6 – Dryopteris aristata. *Longitudinal median section of a shoot apex, showing the apical meristem, with its conspicuous apical cell, a leaf primordium (left), scales (left and right), and the incipient vascular tissue which originates immediately below the apical meristem.* (× 126.)

FIGURE 7 – Dryopteris aristata. *Part of the shoot apex, in longitudinal section, showing the distinctive meristematic cells. The conspicuous superficial cell (left) is the primordial cell of a leaf.* (× 240.)

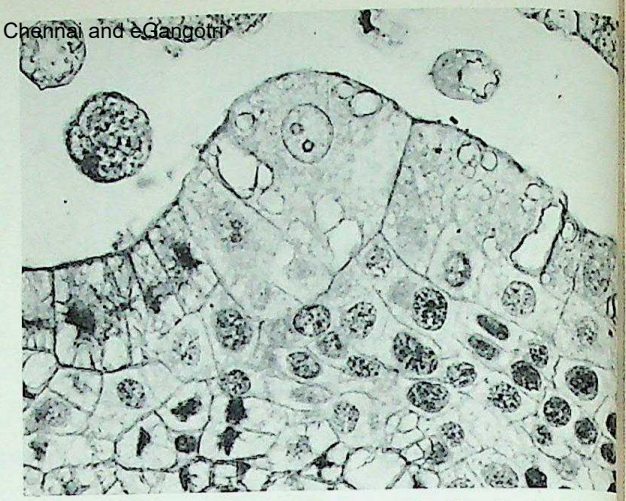

FIGURE 8 – Dryopteris aristata. *Median longitudinal of a leaf primordium at a very early stage of development.* (×

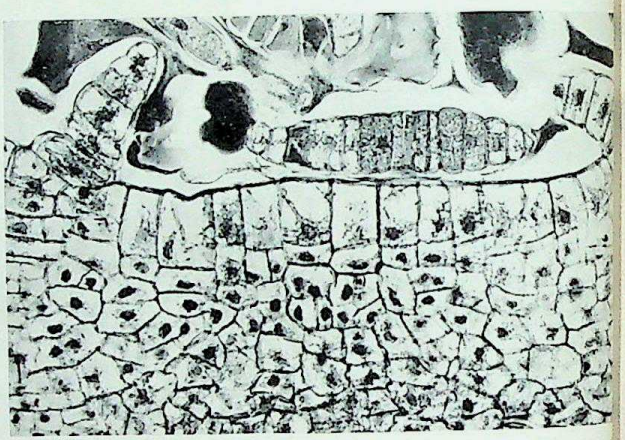

FIGURE 9 – Onoclea sensibilis. *Part of a transverse sec a rhizome showing a bud primordium, or detached meristem overlapping protective scales.* (× 225.)

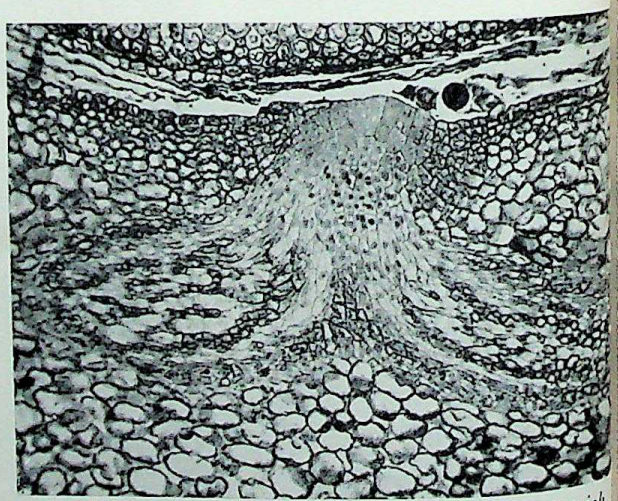

FIGURE 10 – Matteuccia struthiopteris (*The Ostrich Part of a transverse section of an erect shoot showing a meristem developing into a lateral bud. The vascular system bud has become confluent with two conjoined vascular strands rhizome.* (× 90.)

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intrinsic factors, but to extrinsic factors such as increasing size or to the incidence of mechanical factors. In this we see a return to the Hofmeister attitude. An example may be taken from the ferns. During the phyletic period it was held that a vascular system or stele consisting of a solid core of xylem, surrounded by phloem, and known as a protostele, represented an ancient and primitive condition. Such a stele is characteristic of the earlier fossil ferns, and of living ferns regarded as primitive (figure 3); it is also present in the earlier stages of development of other ferns regarded as more advanced and derivative. Another type of stele, described as a solenostele, consisting of a cylinder of xylem with external and internal phloem and a central pith (figure 4), was regarded as being a later or derivative type. In general this type of stele occurs in ferns which are considered to occupy an intermediate position in the systematic scale. Yet a further stelar development is seen in the dictyostele (figure 5), in which the essentially cylindrical stele is perforated by wide parenchymatous leaf-gaps or meshes, so that the actual vascular tissue consists of an open meshwork. The dictyostele, which is characteristic of the most advanced modern ferns, is preceded, in individual development, by protostelic and solenostelic stages. Now, during the phyletic period, the facts of stelar morphology appeared to make a coherent and substantial thesis, namely, that stelar structure afforded one of the most useful criteria for comparative purposes, the more so as it was held that the vascular tissues were among the 'most conservative' of those to be observed in the plant. But in 1921 a new point of view was announced when Bower showed, by a wide survey of pteridophyte steles, that elaboration of form went hand in hand with an actual increase in size, physiological and mechanical factors in one way or another being causally implicated. With this observation necessarily goes the view that to the extent that structural features can be explained by causal factors, such as the size-factor, so do these features lose their value for comparative purposes and as evidence of progressive change during descent.

When one door closes, another opens. As interest in comparative studies waned, it began to be realized that, even if the phyletic history of plants were before us in full, the problems of causal morphology, i.e. the investigation of the factors relating to the assumption of form, would still remain, and that these were, as Hofmeister had so well understood, of the very essence of biological inquiry. That is, in effect, the position today: we realize that we know very little concerning the factors which influence the development of the form and structure of plants—on which data the comparative morphologists depended for their generalizations.

The past three decades have thus witnessed a marked tendency on the part of botanists to turn away from purely comparative studies to investigations of the process of development. In this study physiology has an important place. But such studies should include a consideration not only of the factors which influence the development of form and structure in the individual, but of development in its wider evolutionary sense and of the driving forces which bring it about. In the problem thus indicated, plant anatomy and experimental morphology have their place. Because of their simpler structural features the ferns, as compared with flowering plants, are regarded as affording favourable materials for investigations.

The contemporary view may be stated as follows. In vascular plants the shoot apex is the seat of all primary formative activities: all lateral appendages, leaves, scales, and buds (excepting those which are adventitious) originate at or near the apex; so, too, do all primary tissue systems. Thus, if we would understand how the external form and internal structure of any vascular plant come to be what they are, we must investigate, by all the means at our disposal, formative (or morphogenetic) processes at the apex throughout the development of the individual. Thus we return, as it were at a higher level, to a working system not greatly dissimilar to that which obtained one hundred years ago. Contemporary studies are essentially dynamic in outlook. The ferns, in particular, have proved of great value in this work, for not only do they possess a very distinct and characteristic apical meristem, with, usually, a conspicuous apical cell (figures 6, 7), but in ferns such as the Male Fern (*Dryopteris filix-mas*) or the Broad Shield Fern (*D. aristata*), the individual leaf primordium originates from a single meristematic cell (figures 7, 8). Moreover, the incipient vascular tissue can be traced to a region which immediately underlies the apical meristem, and this has given rise to the hypothesis that the initial differentiation of vascular tissue may be referred to the basipetal diffusion of a substance or substances from the active meristematic cells (figure 6).

In experimental work, buds may afford favourable materials for the investigation of developmental

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processes. In the ferns, the study of the positional relationship and development of buds has yielded many points of interest. As in flowering plants, the lateral buds of ferns are inhibited by substances which proceed from the actively growing shoot apex: the destruction of the apex is usually attended by a more or less rapid growth of lateral buds. According to the proximity of the lateral bud to the apex, its vascular tissue may make a more or less complete conjunction with that of the parent shoot (figure 10) or, as in older regions, no conjunction whatsoever may be effected. As to the origin of buds, there is a question as to what relationship, if any, they bear to the apical meristem. Recent fern investigations have confirmed an earlier finding that there is a unity of origin of meristematic, i.e. formative, tissue throughout the plant: in other words, each bud primordium, consisting of superficial meristematic cells, is originally part of the apical meristem of the shoot, but becomes detached and separated during the process of growth. Such buds, or primordia, which have been described as detached meristems (figure 9), tend to occur and persist in definite positions along the shoot, and will grow into lateral shoots when the physiological dominance of the terminal meristem is removed.

In many ferns parenchymatous gaps typically occur in the shoot stele opposite the leaf-bases. The resulting characteristic dictyostele has been discussed and 'explained' in different ways, and, as we have seen, has been used in comparative studies. The relative importance of the axis or shoot and of the leaf in contributing to the vascular system has also been the subject of much discussion. For example, it has been asserted that the vascular system of the shoot is built up from the decurrent vascular strands of the leaves—that there is, in fact, no stele that is truly of axial origin. That a direct relationship exists between leaf development and the internal morphology of the shoot, and that a truly axial stele does exist in ferns, can be tested by experimental means. It has been shown that if a succession of very young leaf primordia of *Dryopteris* spp. is destroyed, the formation of the corresponding parenchymatous leaf gaps is prevented, and the vascular system of the shoot, which does in fact develop, is a solenostele, and not a dictyostele as in the normal shoot.

It has also been possible to perform a number of other experimental operations on the delicate apical region of ferns. Space does not permit of a discussion of the results which have been obtained, but, briefly, they disclose the surprising extent to which this very delicate region can be manipulated, and how varied are the morphological and structural changes that can be induced. The meristematic or formative region thus shows what has been described as considerable morphogenetic plasticity. The results of one series of experiments indicate that the idea that the vascular system of ferns is highly conservative in its nature can no longer be maintained. Nutritional, mechanical, and spatial factors are seen to be important in influencing the distribution of tissues in the growing region and therefore the ultimate pattern.

It will be evident that to the physiologist also, the growing region affords a host of problems of the greatest interest and importance. This region is, *par excellence*, the seat of formation of protoplasm and therefore of protein synthesis. From it proceed substances, such as the auxins, which exercise important effects in other parts of the plant. Thus the interest of the biochemist also becomes enlisted. For an adequate physiological investigation of the small but all-important formative region, new and refined technical methods will be required; but the data which should accrue, when integrated with those of the morphologist, will undoubtedly advance our knowledge of the process of development and render it more full and coherent. Reference should also be made to yet another aspect. The relation between genes and developmental processes has only recently begun to receive the attention which the subject so evidently deserves. At present very little is known about the actual physiological expression of a gene—how, where, and when it exerts its influence. The results in many instances, though not in all, are seen in the manifestation of characteristic formal and structural features during development. Here again it may be anticipated that the integration of the data of the two branches, genetics and morphology, will be attended by new and significant advances.

This brief account must serve as an indication of the interest and scope of experimental morphology. Clearly the results, when integrated with those of other branches of botany, should eventually have a two-fold interest. In the first place, they should provide at least partial answers to the questions propounded by Hofmeister some eighty years ago; and secondly, they should prepare the way for a critical re-examination of what must always remain one of the central and fundamental problems of biology, namely the course of descent and the process of evolution.

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The metabolism of the oestrogenic hormone

G. F. MARRIAN

Recent research on the oestrogenic hormones has been marked by the increasing attention paid to the investigation of the chemical changes they undergo in the body. This investigation is a first step towards an understanding of the nature of the reactions involved when these substances produce their physiological effects. Professor Marrian here reviews our present knowledge in this field of biochemistry, and indicates lines of possible future progress.

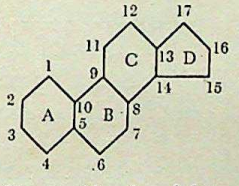
INTRODUCTION

In female animals the growth of the uterus and vagina which occurs at puberty, and the characteristic changes which occur in these accessory sex organs during 'heat' or oestrus, are produced by a physiologically active principle which is secreted by the ovary into the blood stream. If the influence of this 'oestrogenic hormone' is removed by extirpation of both ovaries, the accessory sex-organs soon become atrophic and the changes in them typical of the oestrous cycle are no longer seen. It is possible, however, to induce artificially the characteristic oestrous changes in the uterus and vagina of such an ovariectomized animal by the injection of a suitably prepared extract of ovarian tissue.

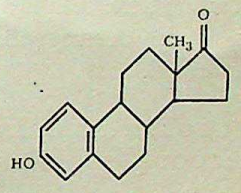
Two closely related oestrogenic substances, oestrone (I) and α-oestradiol (II), have been isolated from ovarian tissue in the chemically pure state. They possess the carbon skeleton of 1.2-*cyclo*-pentenophenanthrene and are therefore classified as steroids. As little as $\frac{1}{2000000}$ mg. of α-oestradiol is sufficient when injected subcutaneously into an ovariectomized mouse to induce the typical oestrous changes in the vagina. Since oestrone is somewhat less potent than α-oestradiol in inducing vaginal oestrus in ovariectomized animals, the latter is commonly regarded as being the true oestrogenic hormone.

In man and the horse oestrogenic substances are excreted in the urine in large amounts during pregnancy, and several of these urinary oestrogens were isolated, and their structures determined, some years before the isolation of the two ovarian oestrogenic substances. The urine of pregnant women contains, in addition to oestrone and α-oestradiol, a third oestrogen, oestriol (III). The latter is present in human pregnancy urine in much larger amounts than are oestrone and α-oestradiol, but it is less potent than the two latter in inducing vaginal oestrus in ovariectomized animals.

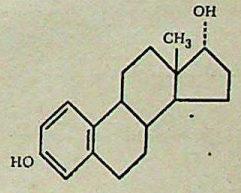
No fewer than six different oestrogenic substances have been isolated from the urine of pregnant mares. In addition to oestrone and α-oestradiol, the C_{17} stereoisomer of the latter, β-oestradiol (IV), equilin (V), equilenin (VI), and 17-dihydroequilenin (VII) have been isolated



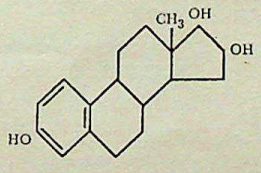
The steroid carbon skeleton



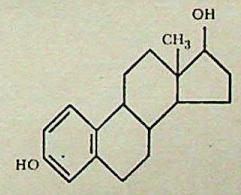
(I) *oestrone*



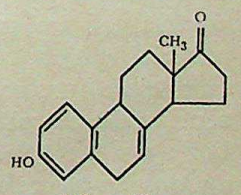
(II) *α-oestradiol*



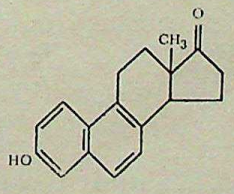
(III) *oestriol*



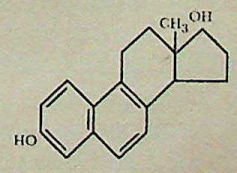
(IV) *β-oestradiol*



(V) *equilin*



(VI) *equilenin*



(VII) *17-dihydroequilenin*

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from this source. It is interesting to note that oestriol has not so far been isolated from the urine of pregnant mares, while equilin, equilenin and 17-dihydroequilenin have not been isolated from the urine of pregnant women.

It is probable that the oestrogens which are excreted in such large amounts in the urine during pregnancy may be formed in the placenta rather than in the ovary. The evidence favouring this view is briefly as follows: (i) In women and in mares the amount of oestrogen excreted in the urine falls very sharply immediately after delivery; (ii) it has been observed that in women who have undergone an operation for double ovariectomy during pregnancy the level of oestrogen excretion in the urine remains high in spite of the absence of the ovaries; (iii) the same three oestrogens which occur in human pregnancy urine—oestrone, α-oestradiol, and oestriol have also been isolated from human placenta.

During recent years, research on these oestrogenic substances has entered upon a biochemical phase, in which the reactions undergone by them in the animal body have been investigated. It may be said that the ultimate object of the biochemical investigations is the elucidation of the nature of the chemical reactions involved when these substances produce their physiological effects. Although this object is still far from realization, a considerable amount of interesting information concerning the various transformations which the oestrogens may undergo in the body has been accumulated. In this article some of this recent biochemical work on the oestrogenic substances will be briefly reviewed.

CONJUGATED OESTROGENS IN URINE AND BLOOD

In the early days of the study of the urinary oestrogens it was observed independently by a number of workers that the yield of active material which could be extracted by water-immiscible organic solvents, such as ether or benzene, could be greatly increased by a preliminary boiling of the urine with acid. From these observations it was concluded that a considerable fraction of the oestrogen in both human and equine pregnancy urines was not present in the free state, but was combined in some way rendering it more soluble in water and less soluble in the water-immiscible organic solvents.

Two of the combined urinary oestrogens have so far been isolated and characterized. In 1936, Cohen and Marrian isolated an oestriol monoglucuronide from human pregnancy urine, and subsequently showed that the glucuronic acid was joined by a glucosidic linkage to either the C_{16} or C_{17} hydroxyl group of the oestriol. Schachter and Marrian (1936) showed that the oestrogens in pregnant mare's urine were mainly present as sulphuric acid esters, and subsequently (1938) they were successful in isolating from the same source the potassium salt of oestrone sulphuric acid in small yield. The work of Butenandt and Hofstetter (1939) has shown that the oestrone in human pregnancy urine is probably also present as the sulphuric acid ester. So far there is no evidence that oestriol occurs naturally as a sulphuric acid ester or that oestrone occurs as a glucuronide.

The occurrence of conjugated oestrogens is not limited to the urine. Human placenta contains a water-soluble conjugated form of oestriol (Collip *et al.*, 1934). While this conjugate has not yet been isolated as a pure substance, it seems likely that it may be an oestriol monoglucuronide identical with that present in human pregnancy urine. Mühlbock (1937, 1939) showed that the amount of oestrogen extractable by water-immiscible fat solvents from the blood of pregnant mares and of pregnant women could be increased by a preliminary boiling with acid. The presence of water-soluble conjugated oestrogen in the blood of pregnant women has been recently confirmed by Rakoff *et al.* (1943). These authors have put forward evidence, which does not appear to be entirely conclusive, that the blood oestrogen may be bound to the serum proteins. Since the conjugated oestrogen in blood is clearly the 'transport' form of the hormone its isolation in a state of chemical purity and its characterization would obviously be most desirable.

THE INTERCONVERSION OF OESTRONE AND THE OESTRADIOLS IN THE ANIMAL BODY

The occurrence of the two stereoisomeric oestradiols together with oestrone in the urine of pregnant mares suggests that the former may both be formed from oestrone by the reduction of the ketonic group. There is, indeed, direct evidence that such a reduction actually occurs in the animal body. Stroud (1939) has isolated β-oestradiol from the urine of rabbits after the administration of oestrone, while Pearlman and Pincus (1942) have detected the presence of α-oestradiol in the urine of men following oestrone administration.

The experiments of Heard and his co-workers (1941) have provided evidence not only for the reduction of oestrone in the body, but for the

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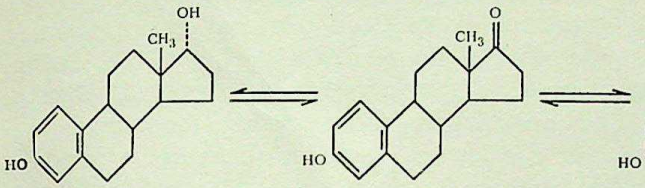
oxidation of oestradiol to oestrone. Following the administration of α-oestradiol to rabbits and to a man they were able to isolate both oestrone and β-oestradiol from the urine in the first case and oestrone alone in the second. Heard's findings with rabbits have been confirmed by Fish and Dorfman (1942).

There are therefore good grounds for believing that the two oestradiols and oestrone are to some extent interconvertible in the animal body, as shown in the following scheme:



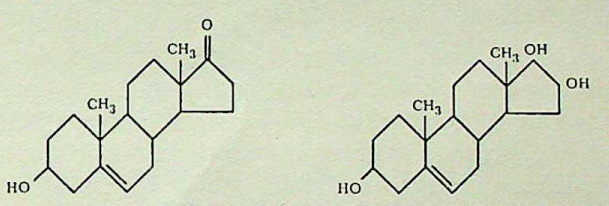
α-oestradiol *oestrone* *β-oestradiol*

THE CONVERSION OF OESTRONE TO OESTRIOL

In 1937, Pincus and Zahl claimed to have demonstrated the excretion of oestriol in the urine of rabbits following the administration of oestrone. In these experiments, however, the presence of oestriol was inferred from a colour reaction and was not confirmed by isolation and characterization of the pure substance. More recently Heard and his co-workers (1941), and Fish and Dorfman (1942), have failed to isolate oestriol from the urine of rabbits and guinea pigs after the administration of oestrone.

There is, however, good evidence that in man oestrone may be converted into oestriol. Following the administration of a large amount of oestrone to a young man, Pearlman and Pincus (1942) have isolated oestriol from the urine in a small yield and have satisfactorily characterized it. It does not necessarily follow from this, however, that the oestriol found in the urine of pregnant women is formed in the body from oestrone or α-oestradiol and is merely an end-product of the metabolism of these oestrogens. It is at least possible that oestriol may be directly synthesized in the human placenta, and that it may have some specific but so far unknown functions during pregnancy.

It seems possible that other 17-ketosteroids besides oestrone may be transformed in the body to steroids with hydroxyl groups at positions 16 and 17. Hirschmann (1943) has recently isolated from the urine of a boy with a tumour of the adrenal glands a steroid belonging to the male hormone series which has hydroxyl groups at positions 3, 16, and 17. It is an attractive hypothesis that this Δ^5-androstene-3, 16, 17-triol may bear the same structural and biological relationship to dehydroisoandrosterone[1] as does oestriol to oestrone. However, until it has been shown that the steric configurations of the C_{16} and C_{17} hydroxyl groups are the same in this androstenetriol and in oestriol, and until it has been definitely proved that the former compound can be produced in the body from dehydroisoandrosterone, this hypothesis must be viewed with some caution. It has been shown recently by Marrian and Butler (1944) that the same androstenetriol is present in small amounts in the urines of normal men and women. It is evident therefore that the metabolic path by which it is formed in the body is a normal one.



Dehydroisoandrosterone *Δ^5-androstene-3 (α), 16, 17-triol*

DEHYDROGENATIONS AND HYDROGENATIONS IN THE OESTROGEN CARBON SKELETON

Evidence of a rather inconclusive nature is accumulating which indicates that dehydrogenations and hydrogenations of the oestrogen ring system may occur in the body, in addition to the oxidations and reductions of the substituent groups which have been discussed above.

In the mare, as pregnancy advances, the amounts of equilin and equilenin, relative to the amount of oestrone, increase. On the basis of these facts it has been suggested that equilin and equilenin may be formed in the mare by successive partial dehydrogenations of oestrone. This suggestion is not one that can be easily tested by direct experimentation, as will be readily understood.

The possibility that the aromatic ring in oestrone may undergo complete hydrogenation in the

[1] Dehydroisoandrosterone is a steroid possessing androgenic activity which is found in the urine of both men and women. Since the amounts of this steroid excreted in the urine are greatly increased in certain cases of cancer or enlargement of the adrenal glands, and since it is still excreted after removal of the testes or ovaries, it is generally believed that it originates in the adrenal glands.

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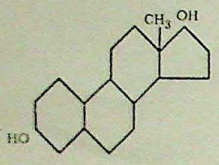
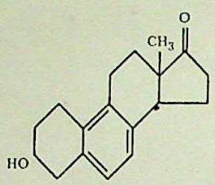
body was raised by the isolation by Marker *et al.* (1938) of two isomeric oestranediols from the urine of non-pregnant women. These oestrogen reduction products were not found in the urine of pregnant women, and accordingly Marker *et al.* suggested that their formation may be associated with the normal utilization of the hormone in the menstrual cycle.



oestranediol



$\Delta^{5,7,9}$-*oestratriene-3-ol-17-one*

Further indirect evidence favouring the view that ring A in the oestrogen molecule may undergo complete hydrogenation in the body was obtained when Heard and Hoffman (1940, 1941) isolated $\Delta^{5,7,9}$-*oestratriene-3-ol-17-one*, a bond isomer of oestrone in which ring B instead of ring A is aromatic, from the urine of pregnant mares. Since it has been shown by Ruzicka *et al.* (1938) and by David (1938) that $\Delta^{5,7,9}$-*oestratriene-3,17-diol* can be formed from equilenin by reduction with sodium and ethanol, Heard and Hoffman suggest that $\Delta^{5,7,9}$-*oestratriene-3-ol-17-one* may be formed in the body from equilenin by an analogous preferential hydrogenation of ring A.

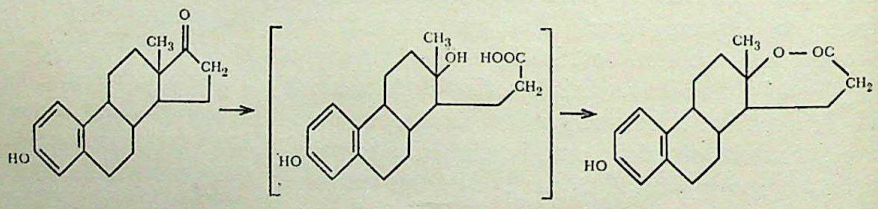
OESTROGEN INACTIVATION IN THE ANIMAL BODY

It has been demonstrated by a number of different workers that only a small fraction of the activity of oestrogen administered to animals can be satisfactorily recovered from the excreta and the carcase. It is evident therefore that the animal body possesses considerable powers of inactivating administered oestrogens, and it is therefore reasonable to assume that much of the endogenous oestrogen is similarly inactivated.

A considerable amount of evidence has been accumulated which indicates that the liver may be the principal site of oestrogen inactivation in the body. Thus Zondek (1934) showed that oestrogen was inactivated *in vitro* in the presence of liver mash but not in the presence of the mash of other organs, while more recently Heller *et al.* (1939) have shown that oestrogens are inactivated by slices of rat liver but not by slices of rat lung, spleen, or uterus. Israel *et al.* (1937) found that oestrogen perfused through a heart-lung preparation was inactivated when the liver was in the circuit, but was not inactivated in the absence of the liver.

It is believed by some that oestrogen inactivation in the liver may be the result of an enzymic oxidation process, although the enzymic system responsible has not yet been characterized, nor has any physiologically inactive oxidation product of an oestrogen been isolated so far from animal tissues or excreta. In this connection, however, the work of Westerfeld (1942) is of considerable interest. On treatment of oestrone in alkaline solution with hydrogen peroxide at room temperature for several days, he obtained as the main product the lactone of an acid formed by the rupture of ring D between carbon atoms 13 and 17. Since the course of oxidation of many substances in the animal body can be imitated in the laboratory by oxidation with hydrogen peroxide it is possible that the inactivation products of oestrogen in the body may be substances of this type, although Heard and Hoffman (1941) failed to isolate any such compound from the urine of a man after the administration of large amounts of oestrogen.

Recent work by O. W. Smith (1944) suggests that oestrogen oxidation products of the type of Westerfeld's lactone, if they are actually formed in the body, may be of considerable physiological importance. It has been known for many years that the administration of oestrogens to animals stimulates the activity and increases the size of the anterior lobe of the pituitary gland, secondary results of this stimulation being a partial exhaustion of the gonadotrophic activity of the gland and an increase in the size of the adrenal glands owing to increased production of the pituitary adrenotrophic factor. As a result of the very extensive observations made by himself and his co-workers on oestrogen excretion in women, Smith developed the theory that certain of the physiological effects generally ascribed to the oestrogens, and in



Oxidation of oestrone by hydrogen peroxide

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particular the effect on the arterior pituitary gland, might be due to oestrogen degradation products formed in the body rather than to the oestrogens themselves. Smith was therefore led to investigate the pituitary-stimulating action of Westerfeld's lactone. It was found that this compound, which possesses only a small fraction of the oestrogenic activity of oestrone when tested by the usual method involving the production of the characteristic oestrous changes in the vaginae of ovariectomized animals, was considerably more potent than oestrone in its effect on the anterior pituitary body. This extremely important finding suggests the possibility that the physiological significance of oestrogen inactivation in the body may be much greater than has been hitherto supposed, and it should undoubtedly stimulate a more thorough investigation of the chemical nature of the inactivation process.

Campbell and Hey (1944) have recently pointed out that the oestrogen content of different urines (human, mare's, and stallion's) is roughly proportional to their content of *p*-cresol. They therefore suggest that tyrosine may not be the only source of the urinary *p*-cresol as is usually supposed, and that some of the latter may be derived from the degradation of oestrogens and other steroids in the body. It is to be hoped that this interesting suggestion will be followed up by a direct experimental attack.

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Book reviews

AN EXPERIMENTAL COURSE IN OPTICS

Practical Optics, *by B. K. Johnson. Pp. viii + 189. The Hatton Press Limited, London.* 1945. 15*s. net.*

When an author has a wealth of experience both of teaching and of practising his subject, it is inevitable—given moderate fluency—that he should produce a competent work. These are, in fact, the qualities which B. K. Johnson has brought to bear on the writing of *Practical Optics*.

The experiments of the earlier chapters, which illustrate the paths taken by the image-forming light through optical components and systems, should very soon find a place in elementary courses on light.

In Chapter III the principles of the telescope are dealt with in adequate detail. It is a pity that the treatment is marred by a seriously misleading representation of the 'star-test' appearances of aberrated and aberration-free objectives. The reader would be well advised to consult the photographs in H. D. Taylor's *Testing and Adjustment of Telescopic Objectives*.

In dealing with the microscope, resolution is calculated assuming non-coherent star objects instead of a periodic structure with phase-related illumination. This latter leads to Abbe's formula, which is the one usually given. The section on ultra-violet microscopy is one where the author can (and does) speak with undeniable authority. In contrast, the developments in photographic lenses of the last twenty or thirty years are completely, and unjustifiably, ignored.

There are two typographical errors: in the spelling of *Amphipleura* (p. 83), and in fig. 127, which reads Coolne instead of Cooke. These will no doubt be corrected in a second edition, which this book deserves, and which it should get.

H. H. HOPKINS

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INTERPRETATION OF PERIODIC WAVES

Wave-form Analysis, *by R. G. Manby. Pp. xi* + 275. *Chapman & Hall Limited, London.* 1945. 21*s. net.*

Mr Manby has written this book as a result of his experience in the Vibration Department of the de Havilland Aircraft Company. The book might appropriately be renamed, 'What every young engineer should know about Fourier Series.' The young engineer should know a considerable amount. The book contains mathematical chapters discussing Fourier's theorem itself, and giving the expansion of many functions of different types. The greater part of the book, however, deals with the practical technique of wave-form analysis as practised in an engineering concern. From, for instance, a strain gauge record, it was required to estimate as accurately as practicable the amplitudes and frequencies of the principal constituents of the waves. When the author first undertook this work, he found that very little published information was available about the technique for doing this. He therefore developed his own technique, and this book was the result. It should be invaluable to anyone faced with a similar task. Besides the purely mathematical chapters, the practical methods of analysis are discussed in detail, including mechanical aids. There are also numerous illustrations of vibration records obtained in practice. One chapter is devoted to Lissajou figures.

N. F. MOTT

ANALYSIS OF ORGANIC COMPOUNDS

Organic Reagents for Organic Analysis, *by the Staff of the Research Laboratory of Hopkin & Williams Limited. Pp.* 172. *Hopkin & Williams Limited, London.* 1944. 5*s.* 6*d. net.*

This small volume lists the most important reagents for the following: carboxylic acids; alcohols; aldehydes and ketones; alkaloids; amides; primary, secondary, and tertiary amines; barbituric derivatives; ethers; halides; aromatic hydrocarbons; mercaptans; nitriles; phenols; sulphonamides; and sulphonic acids. Selected references to the original literature are included. In accordance with the authors' aim—'the use of organic reagents in preparing derivatives of organic substances for purposes of identification by melting points'—the various substances are divided into 'selected reagents' and 'other reagents,' and experimental details and melting points are given only for the former. The choice is governed largely by the accessibility and stability of the reagent, by the ease with which derivatives can be prepared and purified, and by the diversity of melting points for closely related compounds. In checking some of the published melting points, the authors have found 'a surprisingly large number of cases where the literature and reference books are contradictory and inaccurate.' Tables of melting points of the various derivatives of the 'selected reagents' are given at the end of the book.

All who are interested in qualitative organic analysis will find this book useful and will doubtless wish to possess a copy. Its utility would be increased by the provision (*a*) of more experimental details where these are not given in the text, and (*b*) of alternative experimental methods (where available) in applying some of the reagents. The book is well produced; there is a good index.

A. I. VOGEL

STRUCTURE OF INORGANIC COMPOUNDS

Structural Inorganic Chemistry, *by A. F. Wells. Pp. viii* + 590. *Clarendon Press, Oxford.* 1945. 25*s. net.*

We owe the first seeds of structural inorganic chemistry to the early work of the Braggs a quarter of a century ago, when they applied X-ray analysis to rock-salt and other cubic crystals. After some years of slow but steady development the subject branched out astonishingly in many directions and its growth became almost rank. As a result of this accurate new information the structures of many substances such as bleaching powder, lead oxides, phosphorus pentachloride, and the silicates have been shown to be very different from those deduced by earlier chemistry. Many new problems have appeared and have been answered, especially relating to metals, with an enormous widening of the chemist's understanding of the properties of atoms and molecules.

This book gives a very comprehensive account of the results of the above work in inorganic chemistry. The author, though now a crystallographer, has the great advantage of having originally been a chemist, and the book is written as from one chemist to another. The author will earn the gratitude of many for his very clear treatment of each aspect of the subject. The length of the book presents a problem to the unfortunate student. The subject is, however, so various and ramifying, and impinges on ordinary chemistry in so many ways, that almost any mode of arrangement is bound to be hard-going for the newcomer.

E. J. BOWEN

CURRENT METHODS OF COLORIMETRIC ANALYSIS

Colorimetric Analysis, *by Noel L. Allport. Pp. xii* + 452, *with* 37 *tables. Chapman & Hall Limited, London.* 1945. 32*s.* net.

The determination of substances present in very low concentrations and the analysis of very small samples are problems of increasing importance in chemical research. The particular suitability of colorimetry for analyses of this kind, and its convenience in routine analysis where great accuracy is unnecessary, make Mr. Allport's comprehensive account of current methods a valuable addition to chemical literature.

This book is essentially one for the laboratory worker, since theoretical discussions have been deliberately reduced to a minimum. This omission is, however, balanced by comprehensive literature references. The text is divided into a series of monographs devoted to methods used for the determination of specific substances or radicals. The general introduction to each is followed by full practical details of those methods which have been proved reliable after adequate trial. Each method is critically discussed and its limitations are described. Modifications necessary for the analysis of particular materials, such as foodstuffs, are given.

The text is well planned and the over-lapping of subjects largely avoided. The critical approach and frequent references to personal experience stamp the author as a master of his subject. Unlike many enthusiasts, however, he avoids the error of claiming for the methods greater accuracy than they can attain in ordinary practice. This caution is very necessary in discussing colorimetric methods, because of their particular susceptibility to interference by extraneous substances.

Mr. Allport is to be congratulated on a book which is both well written and technically sound and up-to-date. All research workers who use colorimetry will find it a most valuable book of reference.

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ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

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The social functions of science

War-time advances in applied scientific research, of which the development of atomic energy is only one manifestation, have at length opened the eyes of the average man to the fact that, for good or ill, science has become a dominant factor in the daily lives of all the peoples of the world. The governments of the United Nations are rightly paying much attention to the future role of science and scientists in national life, and important decisions are likely to be made during the coming months. It would be regrettable if the present preoccupation with problems relating to the release, control, and employment of atomic energy were allowed to obscure the urgent need for reviewing the future of science as a whole. Of equal urgency is the need that this review should be conducted, as far as is humanly possible, in an atmosphere free from political prejudice and expediency: the commonplace that 'science knows no frontiers' has now become fraught with keener and more imminent significance.

Many recent discussions on the social functions of science will be found on analysis to have dealt with a more specialized subject, namely the social functions of applied science; and that is only a part of the problem. In this issue we publish an article by Mr E. F. Caldin which makes a thoughtful and objective contribution to the question as a whole. In particular, Mr Caldin makes a clear distinction between fundamental scientific research, applied research, and technology. It is perhaps not generally realized outside scientific circles that the war-time progress of science has been made almost entirely in the applied field, and that we have, as it were, been living on our capital knowledge. Comparatively few advances in scientific knowledge of a fundamental kind were made during the years of war. If the recent high rate of advance in applied science is to be maintained, there is a pressing need for a return to the programme of fundamental research, which university laboratories are particularly well adapted to pursue, and in which many of the great industrial corporations are now with welcome vision taking a very active and fruitful share.

Failure to recognize the vital service of fundamental research, by which is meant the investigation of natural phenomena with indifference to utilitarian ends, underlies the vociferous demands made in various quarters for the governmental control of research. Such control would to a large extent defeat its avowed object; for who can issue directions for an untravelled path leading to an unknown destination? Direction is practicable only in the fields of applied science and technology, where the problem is to apply existing knowledge to the satisfaction of specific requirements. This kind of research is undertaken largely in industrial laboratories, and is of course ultimately orientated by considerations of supply and demand. Its full development depends upon the existence of a large reserve of previously unexploited knowledge, the provision of which is one of the functions of fundamental research. The atomic bomb is often quoted by the advocates of control as a shining example of scientific progress under central direction; but in point of fact all the principles on which the bomb is based were firmly established before the war by individual scientists, or small teams of scientists, seeking only to explore new fields of knowledge.

The necessity for the maintenance and encouragement of unfettered fundamental research raises an associated problem of general interest and importance, namely the financial status of scientists. There are very few industries in the world which do not depend to some extent upon the fruits of scientific research, and many which are almost completely dependent. Witness, for example, the electrical, petroleum, coal, steel,

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chemical, and textile industries: and these, under modern conditions, owe as great a debt to the academic research worker as to the applied research worker within the industries themselves. Yet the fact is indisputable that the university scientist receives, on an average, very considerably less financial reward than his industrial counterpart of comparable ability. Furthermore, the industrial scientist himself, as long as he remains at research work, is usually ill paid in comparison with his administrative colleagues. The result is that throughout the world a financial temptation exists tending to attract academic scientists into industrial research and thence to administration. For the good of science, of industry, and of society in general, this continuous and damaging drain of valuable potential should be greatly lessened: not by governmental coercion, but by more adequate financial recognition of the value of both pure and applied research. The great majority of scientists place their work first and are not moved by avarice; but if they are to give of their best they must be freed from constant financial anxiety and afforded the means to live at the level of their social peers. There are few countries, if any, where such a state of affairs exists at present. Attempts at betterment must, however, be ever watchful of control. Within the sphere of fundamental research it is essential that the worker should be entirely free to follow his own bent. Had 'direction' been applied to the great scientists of the past—men like Newton, Galileo, Pasteur, Rutherford—they would no doubt still have done distinguished work, but the world with equal certainty must have been the poorer by some of their most far-reaching discoveries.

The fact has already been stressed that a wider interpretation to the public of the nature and meaning of science is a necessary preliminary to the general recognition of the importance of the scientist in world affairs. With the return of large numbers of scientists from war work to their normal activities, the moment is opportune to repeat the emphasis. Unfortunately, though the interpretation of science must come mainly from scientists themselves, few have been sufficiently interested to essay it, and fewer still have shown themselves competent to do so. But now, when atomic energy warns us that we have entered a new and uncertain era, it is the plain duty of the scientist to place the interpretation of science to the public on the same level of urgency as the actual advancement of knowledge. Even from the narrower point of view of the future of science itself this education of the body politic must be undertaken; for it is to a large and growing extent the general public which in the last resort foots the bill for scientific research, and in order to maintain present support and to seek for a future substantial increase it is right that those most concerned—the scientists themselves—should attempt to make their fellow citizens understand as much as possible of the spirit and results of science. In particular is this necessary for securing the increased support vitally required for fundamental research. The results of applied research, as demonstrated in the radio, telephone, internal combustion engine, aeroplane, and so on, more or less speak for themselves; the essential function of fundamental research is, however, far more difficult to understand, and especial pains should therefore be taken to make its importance clear to everyone. There is no lack of excellent publicity media, capable of reaching every section of the people; and by co-operation between scientists and those directly concerned with these media much valuable work could be done for the public good and for the advancement of science. A central publicity board and information bureau for science would be a governmental finger that no scientist would mind seeing in the scientific pie; but Providence helps those who help themselves, and it is to be hoped that scientists—especially the younger of them—will address themselves with vigour to this important task of interpreting science to others.

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Britain's geological history

O. M. B. BULMAN

For so small a country, Great Britain is unique in the completeness of its geological record. It is therefore not surprising that the foundations of geological science were laid here. Dr Bulman's lucid interpretation of the geological map of Great Britain ably illustrates the truth of the geological principle, established by James Hutton in 1788, that 'the earth may be considered as an organized body . . . in which the necessary decay is continually being repaired in the exertion of those productive powers by which it has been formed.'

In reality, land surfaces have little of that permanence with which they are endowed in the minds of most of us. Rather are they regions of unavoidable decay, where various processes of weathering are steadily breaking down the rocks to sands and muds; and rivers, those almost universal agents of transport, are carrying away the detritus to its ultimate resting-place on the floor of the ocean. That stratified rocks are the sands and muds of bygone ages and have been thus formed out of the erosional debris of pre-existing land-masses began to be appreciated at the end of the eighteenth century, when Hutton could write of 'a system in which old continents are wearing away, and new continents forming in the bottom of the sea.' This recognition brought with it the realization that in their original order of superposition we have the clue to the relative ages of our sedimentary rocks; and on that simple truth rests the whole scientific study of historical geology.

Geological time is vast in relation even to such slow processes as weathering; hills and valleys, against such a time-scale, are but the expression of a passing phase in the smoothing down of a continent to a low-lying, featureless plain. Land cannot for long remain much above sea-level, and the shallower ocean basins will become choked with sediment, unless the earth's crust is in some way thrown into fresh relief. The occurrence in high mountain ranges of sedimentary rocks bearing marine fossils itself implies changes of sea-level so great that uplift of the land is the only rational explanation of the phenomenon.

We still know relatively little of the causes of this rejuvenating crustal movement, which (in Playfair's striking phrase) maintains continuity of superficial processes by 'making the decay of one part subservient to the restoration of another.' In general terms, there must be periodic adaptations of the outer crust of the earth to the cooling and shrinking interior; but other factors are certainly involved as well. Such spasms varied in severity, sometimes involving intense folding of the rocks together with faulting (or displacement along planes of fracture), sometimes a hardly measurable distortion; but always they have left evidence through the geological record in the form of breaks in the rock sequence. One of the outstanding contributions of that great pioneer, James Hutton, was his recognition of the geological significance of these physical breaks or unconformities, where newer strata rest upon the eroded edges of an older series. Though greatly in advance of his times, as long ago as 1788 Hutton saw earth history as a succession of upheavals and erosion, alternating with relatively quiescent periods of sedimentation.

Geologically, Britain has been fortunate in having spent so great a part of geological time to seaward of an unstable continent. On balance, submergence has surpassed emergence, deposition has exceeded erosion, and a nearly complete sequence of rocks has been the reward. Indeed, the variety and completeness of our record of the 500 million years or so since life began on this planet is probably, for the size of our country, unique. It is therefore not altogether surprising that the foundations of the study of historical geology were laid here. Of the fourteen systems into which geologists have divided the stratified rocks of the world, only one is missing from our island.

THE GEOLOGICAL MAP OF BRITAIN

A standard geological map depicts so far as possible the known distribution of rocks immediately below the superficial deposits of soil and 'drift,' with colouring or shading to distinguish them according to their age rather than their character. This of itself affords a clue to their inclination and structure, for except as a result of extreme disturbance, the older must underlie the newer. A three-dimensional concept is thus

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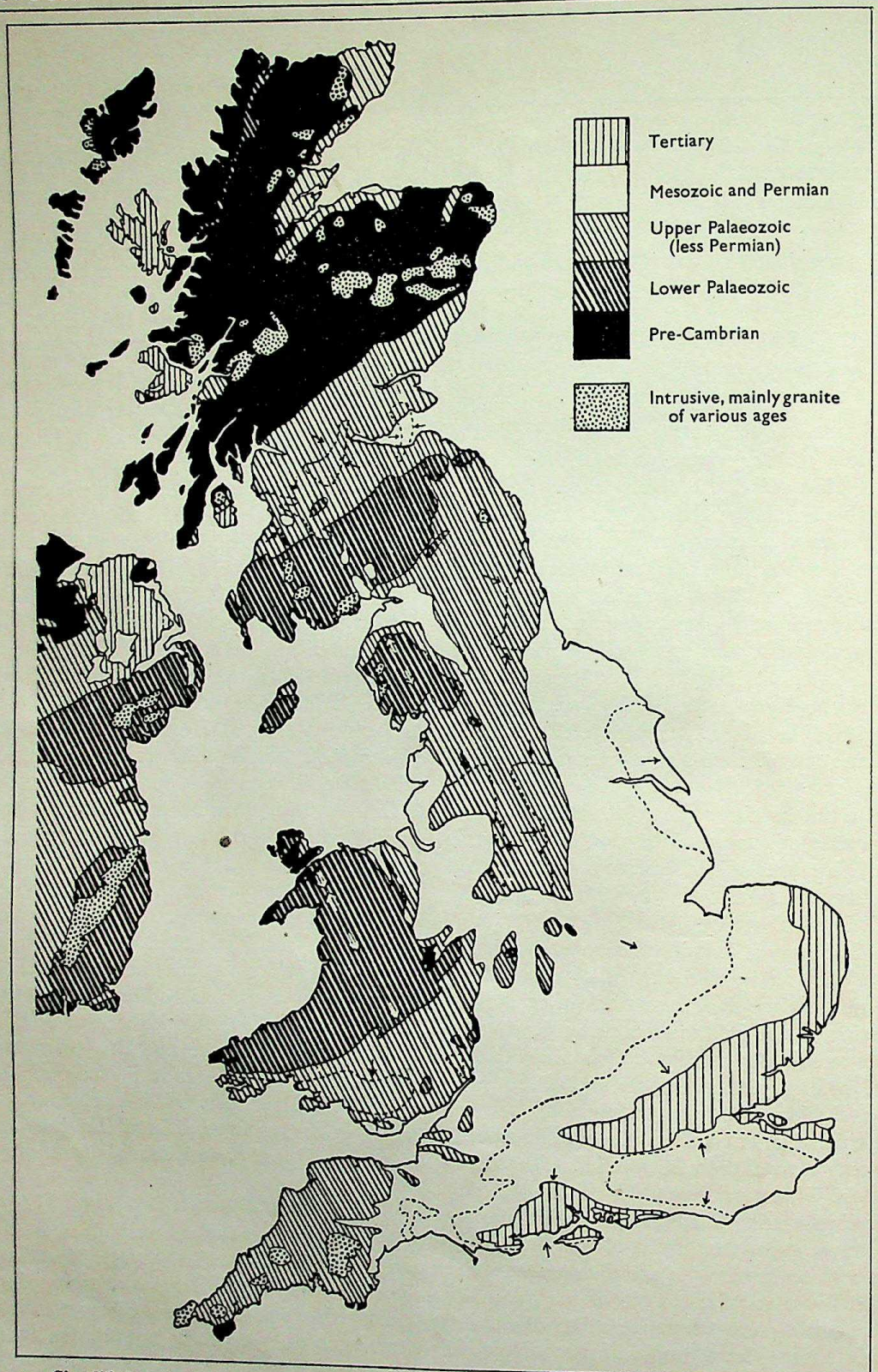

FIGURE 1 – *Simplified geological map of Britain showing the rocks that would appear at surface on removal of the soil and Quaternary (Ice Age) deposits. The highest Palaeozoic system, the Permian, is often classed with the overlying Triassic system as the New Red Sandstone, and outcrops of Permian have here been included with the Trias in the Mesozoic division. Approximate regional dip or inclination of the strata is indicated by the arrows.*

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introduced unobtrusively—the surface distribution reflects an underlying structure. In *making* a geological map, the geologist must express two-dimensionally his conclusions regarding three-dimensional structure, and in *reading* a map he interprets in depth what is presented to him in plan.

Though today situated off the north-western margin of the continent of Europe, Britain has a structural tilt towards the south-east, and for the greater part of her geological history a considerable land-mass lay away to the north and west. Erosion of this now-vanished continent produced much of the detritus which went to make our sedimentary rocks. It is for convenience sometimes referred to by geologists as 'Atlantis,' but its final disappearance must long have preceded the advent of man and his legends. As a result of this persistent structural tilt, however, the oldest rocks are now exposed at the surface in north and north-west Britain, and travelling south-eastwards we are, in general, passing over the edges of successively newer strata bevelled by erosion.

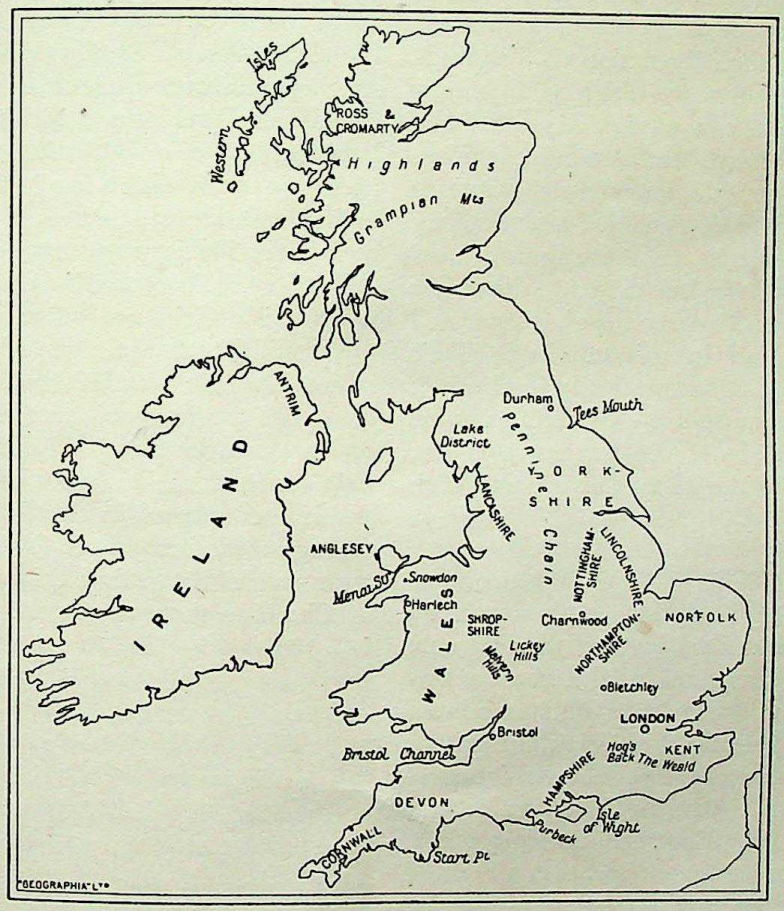

FIGURE 2 – *Key to British place names mentioned in the text.*

Outcropping to the north and west of Scotland and Ireland, with minor exposures projecting apparently haphazard here and there through the cover of newer rocks in Wales, central England, and Cornwall, are the ancient crystalline and sedimentary rocks of the pre-Cambrian, antedating the earliest life of which we have undisputed fossil evidence. These form in themselves a complex succession, representing an interval of time estimated at more than 1,000 million years, and still they do not include anything recognizable as the original crust of the solidifying earth. Here however, we may consider them simply as forming the compact floor underlying the newer, fossiliferous strata.

On this compact formation lie next in order the Palaeozoic[1] (or primary) rocks, outcropping over most of the area between the Scottish and Irish pre-Cambrian and a line drawn from the mouth of the Tees to Start Point in Devon. These rocks are divided into six geological systems, three in the Lower Palaeozoic and three in the Upper, together representing some 300 million years. The upper and lower divisions are separated by an unconformity, marking a period of intense earth movement; the Lower Palaeozoic rocks were much contorted and eroded before becoming buried under newer Palaeozoic strata. Towards the end of Upper Palaeozoic times—between the Carboniferous and Permian systems—there was another such episode, less violent, but again followed by extensive erosion. For simplicity, on the accompanying map and in the account which follows, the Permian system has been included with the overlying Mesozoic[2] division, so that the horizon of this second great unconformity is thus made to coincide with the Palaeozoic/Mesozoic boundary.

Upon these two great superimposed layers of folded and eroded Palaeozoic strata the Mesozoic (or secondary) rocks rest, together representing a period of about 120 million years. They form a more superficial layer, tilted gently to the east and south-east. The regularity of their regional eastward dip is interrupted by two structural depressions, the London and Hampshire

[1] Gr. *palaeos*=old, *zoe*=life.
[2] Gr. *mesos*=middle, *zoe*=life.

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FIGURE 3 – *Schematic section from North Wales to the Weald, summarizing the depositional relations of the sedimentary rock Vertical scale (and hence dips and thicknesses) greatly exaggerated, especially in the south-east.*

Basins, in which remnants of the youngest or Tertiary rocks (deposited during the last 50 to 60 million years) have so far survived the erosion of the present terrestrial phase. These two shallow basins, with the anticline of the Weald arching-up between them, owe their formation to that mid-Tertiary period of disturbance which on the mainland of Europe gave rise to the Alps and the mountain arcs of the north Mediterranean regions.

There are innumerable lesser unconformities throughout the succession, some due to temporary uplift, and others even to no more than a local silting-up of the sea-floor; but these are the major divisions into which earth movement has separated the geological column in this country. Their relations are shown diagrammatically in figure 3; to understand them more fully, we may examine and strip away certain of the successive layers, before reconstructing the history of events which they reveal.

THE QUATERNARY ROCKS

Pleistocene

Removing the superficial layer rather vaguely referred to as 'soil,' we should still find an extensive mantle of boulder-clay and unconsolidated sands and gravels that owe their origin directly or indirectly to the melting of the ice-sheets which overspread so much of Britain during the Great Ice Age. Such deposits are so widespread and superficial that, like the still more recent soil and alluvium, they are omitted altogether from the 'solid' map.

THE TERTIARY ROCKS

Pliocene (*above*)
Miocene (*absent in Britain*)
Oligocene
Eocene (*below*)

Sediments of Tertiary age are practically confined to the London and Hampshire Basins of south-east England (figure 1). Parts of a once continuous sheet, they have become separated through erosion of the crest of the complementary Weald anticline. The sediments are shallow marine or estuarine in character, with some freshwater beds appearing towards the west, and must have been deposited in a shallow sea which probably at no time extended far beyond their present west and north-west boundary. Most of Britain to the north-west was probably dry land, and in this direction rocks of Tertiary age are not found again until we reach the north of Ireland and the Western Isles of Scotland, where they are of strikingly different character. Here occur extensive remains of Tertiary lava flows, poured out over a land surface of pre-Cambrian, Palaeozoic, and Mesozoic rocks, with a few intercalated dirt-bands or fossil soils containing the plant remains by which their early Tertiary age has been established.

Tertiary rocks of south-east England rest everywhere with slight unconformity upon an eroded surface of Chalk, the highest Mesozoic formation, indicating that a brief land period must have separated the Mesozoic and Tertiary eras in this country as over most of Europe. The contact is visible round the margins of the present basins and is encountered in all of the many wells sunk through these formations. To remove the Tertiary rocks would be to find this whole area surfaced by Chalk, as shown in figure 5(*a*).

THE MESOZOIC ROCKS

Cretaceous (*above*)
Jurassic
Triassic (Permian) } New Red Sandstone (*below*)

It might be supposed that, continuing this peeling process downwards through the superposed layers on the Mesozoic, we should uncover successive surfaces likewise continuous over south-east England. Instead, however, deep borings through the Tertiary and Upper Cretaceous rocks of the London Basin pass, not into Lower Cretaceous or even into Mesozoic rocks, but abruptly into Palaeozoic strata; and if for the next layer we stripped away all the Upper Cretaceous rocks we should meet with the unexpected distribution shown approximately in figure 5(*b*). There is thus revealed a fossil plateau, whose existence would be entirely unsuspected from surface evidence alone, over which all but the highest Mesozoic rocks are absent and against whose sloping sides these earlier Mesozoic rocks all thin out. The varying thickness of the formations involved,

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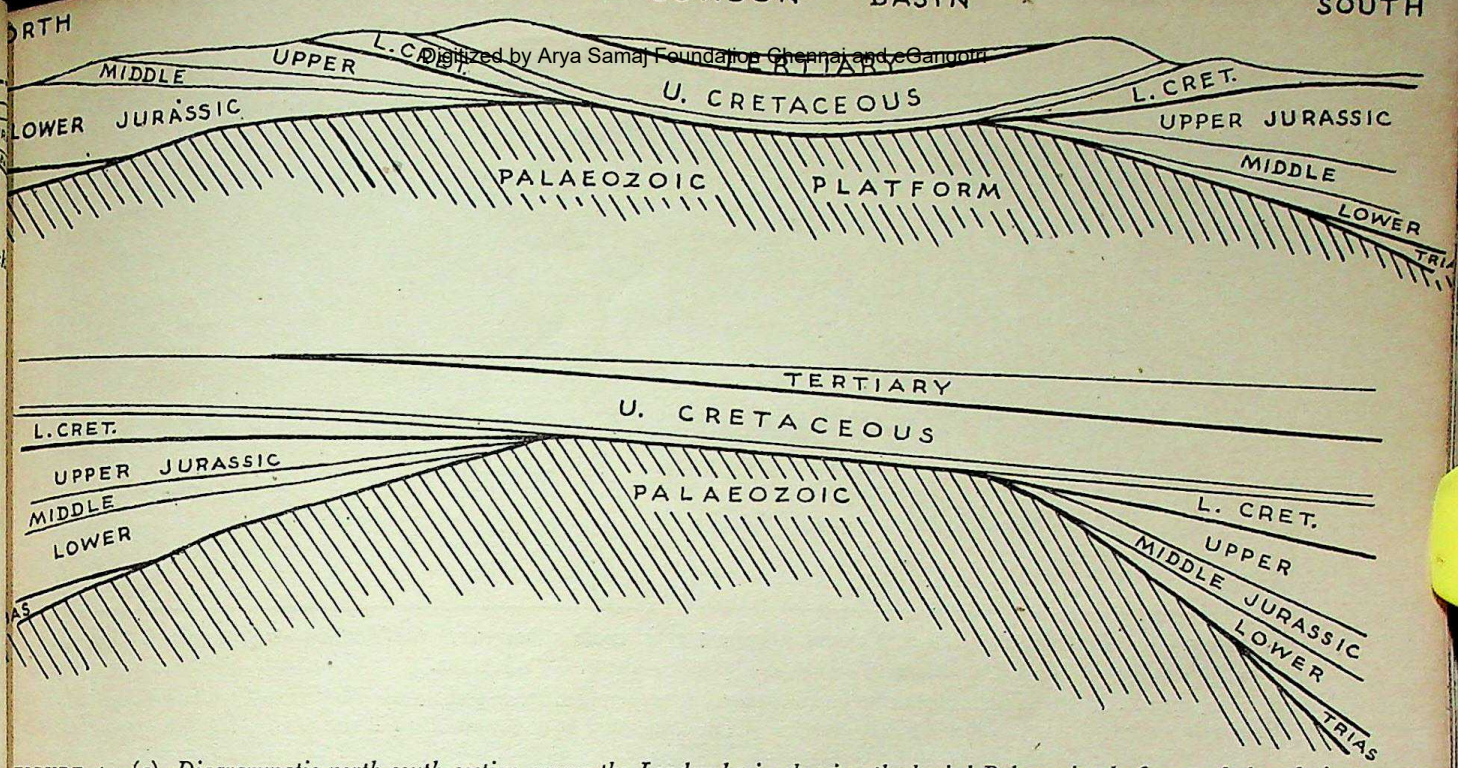

FIGURE 4 – (*a*) *Diagrammatic north-south section across the London basin showing the buried Palaeozoic platform and the relations of the various divisions of the Mesozoic.*

(*b*) *The same, eliminating the Tertiary folding. This brings out more clearly the fact that the Palaeozoic platform stood up as a land area against the shores of which the Lower Mesozoic rocks were deposited. In both sections the inclinations of the strata have been greatly exaggerated.*

determined from bore-holes, enables us to construct the section shown in figure 4 (*a*); and from this it becomes clear (straightening out the Tertiary folding as in figure 4 (*b*)) that this Palaeozoic platform under south-east England must have stood up as a persistent land-mass throughout the greater part of Mesozoic time. Looked at another way, the boundary shown in figure 5 (*b*) approximates to the eastern coastline of the Jurassic and Lower Cretaceous seas. Here is evidence of the irregularity of the surface upon which the Mesozoic rocks were laid down—an irregularity probably accentuated by renewed movement and periodic uplift during the Mesozoic era.

Forming the base of the Mesozoic strata are the reddish marls, sandstones, and pebble beds of the Trias system which, together with the underlying Permian system, are conveniently grouped together as New Red Sandstone. These deposits accumulated in the more low-lying regions between the mountainous massifs of the north and west, and the now-buried Palaeozoic platform to the east.

THE UPPER PALAEOZOIC ROCKS

Carboniferous (*above*)
Devonian (=Old Red Sandstone) (*below*)

The unconformity between the New Red Sandstone of northern England and the folded Carboniferous rocks below is perhaps the most striking in all Britain. It is also the most fully explored, in the development of the economically important coalfield areas.

Carboniferous rocks occupy the greater part of the area shaded Upper Palaeozoic in figures 1 and 13, sometimes separated from the outcrop of older rocks by a strip of Old Red Sandstone, but often overlapping this to rest directly upon islands and massifs of older rock (Lower Palaeozoic, e.g. figure 8, or pre-Cambrian). Stripping away the Mesozoic strata, the area occupied on the map by Upper Palaeozoic, and in particular by Carboniferous rocks, would be very greatly increased; and indeed the Coal Measures of the Upper Carboniferous are worked under a Mesozoic cover over much of the Midlands and the coalfield regions east of the Pennines. But again, not the whole surface thus exposed would be formed of Upper Carboniferous rocks, partly because there are regions where these rocks were never deposited, chiefly because in others again they were eroded away from the crests of folds before the deposition of the Mesozoic rocks. Three large synclines preserved Coal Measures from erosion at the end of the Carboniferous in the now half-exposed and half-concealed coalfields of Durham, Yorkshire-Nottinghamshire, and Lancashire. To the south

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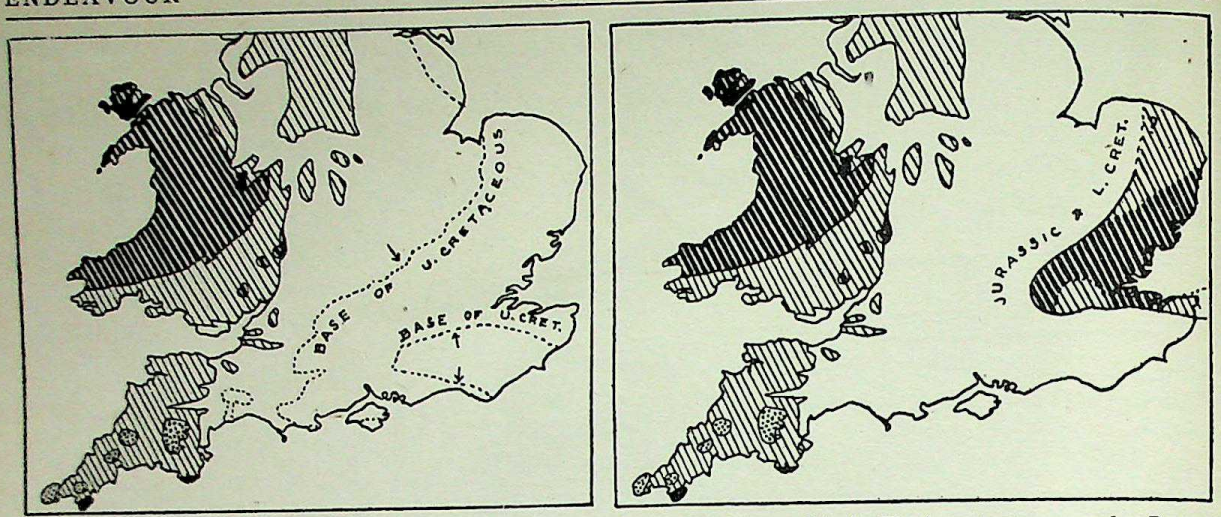

FIGURE 5 – *(a) Southern part of the map shown in figure 1 as it would appear with the Tertiary strata removed. Present outcrops of the base of the Upper Cretaceous shown by the broken line in the Mesozoic.*
(b) The same, with the Upper Cretaceous rocks removed, revealing the buried Palaeozoic platform of south-east England. The Upper Palaeozoic rocks under London are of Old Red Sandstone age; but in East Kent, Coal Measures are worked in a concealed coalfield. Shading as in figure 1.

of the Pennines, a complex fan of structure-lines beneath the Trias determines and separates the various Midland coalfields. Carboniferous rocks are absent from much of the southern Midlands and eastern England, but reappear under the Mesozoic of East Kent and in the semi-exposed Bristol coalfield. The nature of the whole surface forming the floor of the Mesozoic is difficult to predict, because of the rarity of deep borings away from the productive coalfield areas, but some of the known 'snags' or islands of older rock are shown in figure 13, together with the approximate outlines of the known Coal Measure basins.

At the base of the Carboniferous, the Old Red Sandstone occupies extensive pockets in the irregular surface which resulted from the intense 'Caledonian' mountain-building movements at the end of the preceding Lower Palaeozoic era.

THE LOWER PALAEOZOIC ROCKS
Silurian (*above*)
Ordovician
Cambrian (*below*)

Stripping away the Upper Palaeozoic strata would disclose a complex zone of folded and faulted Lower Palaeozoic rocks trending obliquely across Britain, with a belt of pre-Cambrian separating the main Lower Palaeozoic tract of England, Wales, and south Scotland from that of the north-west Highlands. But we do not yet know to what extent the pre-Cambrian would also appear under the Upper Palaeozoic of the Midlands and eastern England. We know of peaks of pre-Cambrian projecting here and there through the cover of Upper Palaeozoic to appear on the Mesozoic floor; on the Upper Palaeozoic floor (revealed by removing the Upper Palaeozoic) their number would surely be greater, and there might well be some relatively large areas of pre-Cambrian. From the characters of the Lower Palaeozoic sediments, we are led to believe that such areas may have occurred in the Irish Sea off the North Wales coast, and over Lancashire; perhaps also in the foundations of the Pennines. Or these and others may have received a thin covering layer of Upper Silurian rocks. A few deep boreholes in eastern England have penetrated to pre-Cambrian rocks in areas where the Upper Palaeozoic is thin or absent (page 51); but this costly exploratory boring is something that geologists hope may one day be undertaken at properly selected sites for its scientific value alone.

THE GEOLOGICAL HISTORY OF BRITAIN

These discontinuous layers of rock shown on the geological map record a sequence of changing geographies and climates which we may now attempt to trace in outline.

The end of the pre-Cambrian era must have witnessed a widespread retreat of the sea and extensive erosion, and in Britain, as elsewhere, the Palaeozoic era begins with a conspicuous marine regression. The pre-Cambrian rocks of the Grampians and Ross and Cromarty

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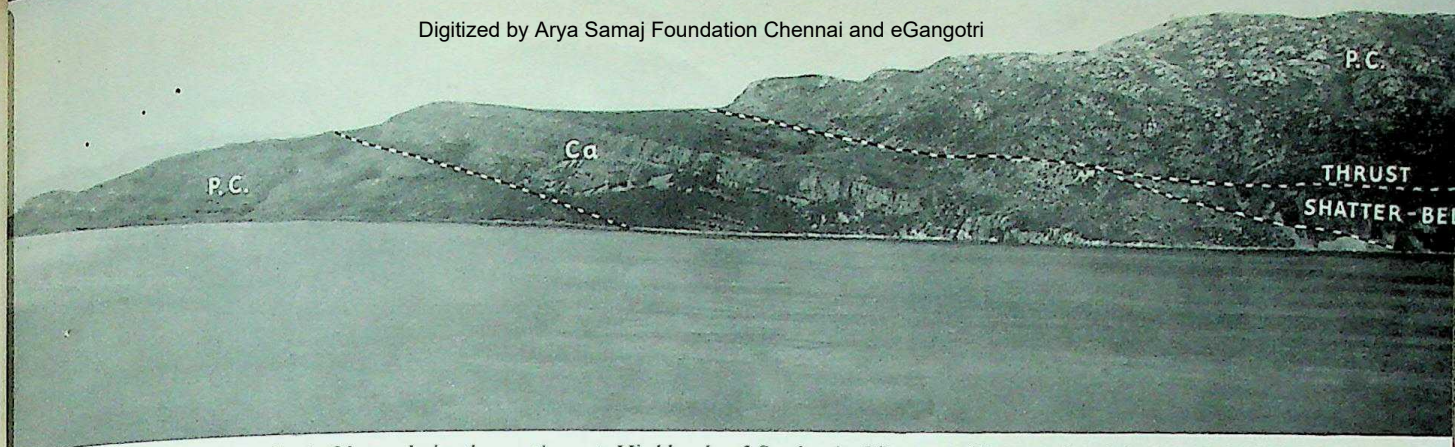

FIGURE 6 – *View across Loch Glencoul, in the north-west Highlands of Scotland. The crystalline pre-Cambrian 'gneiss' (P.C.) in the upper half of the picture, to the right, has been thrust almost horizontally over gently-dipping Cambrian shales and quartzites (Ca), which rest unconformably on the pre-Cambrian (P.C.) forming the headland to the left. Underlying the thrust to the right is a shatter-belt of faulted rocks forming the 'sole' of the thrust-mass.*

(Geological Survey photograph (Crown copyright reserved) to which have been added ink-lines indicating the approximate position of thrust-plane and unconformity.)

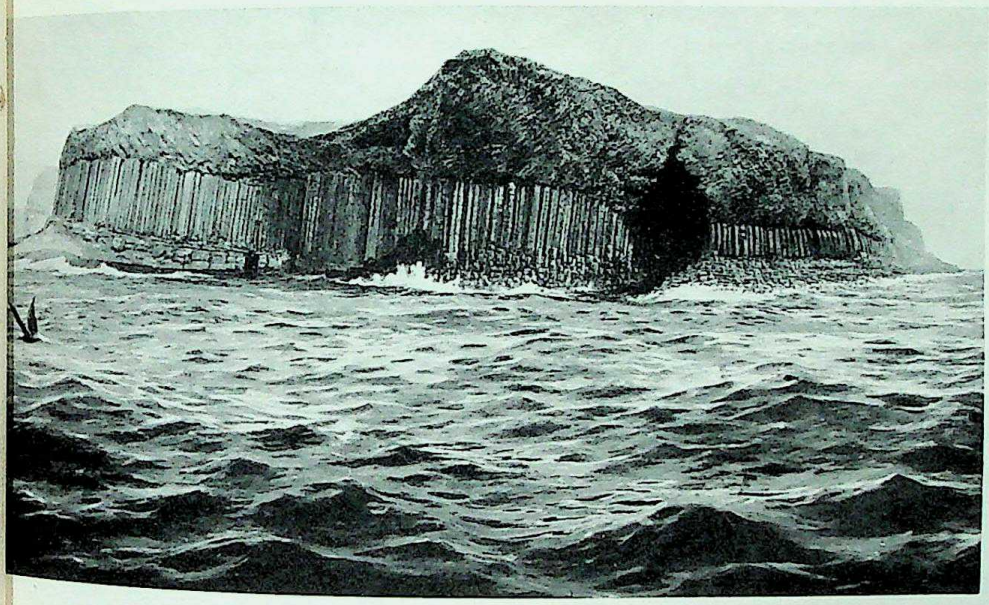

FIGURE 7 – *The Isle of Staffa, off Mull, an eroded remnant of the volcanic plateau of Western Scotland. The basaltic lava flows have developed shrinkage-cracks on cooling, and the lower flow in this figure shows very regular prismatic or columnar jointing. From a diorama in the Geological Museum, London.*

(Geological Survey photograph (Crown copyright reserved).)

FIGURE 8 – *Eglwyseg Mountains, north of Llangollen. Carboniferous limestone forming the bold escarpment rests unconformably on Lower Palaeozoic shales and flagstones of Upper Silurian age. The precise contact is hidden under scree and talus, but Silurian flagstones litter the foreground and make up most of the wooded and low-lying pasture country. The Old Red Sandstone which should separate these two systems is missing and was probably never deposited in this area.* *(Geological Survey photograph (Crown copyright reserved); lettering added.)*

FIGURE 9 – *Snowdon from the east, with Llyn Llydaw in the foreground. The mountain has been eroded out of a syncline of Ordovician volcanic rocks with the highest beds of fossiliferous ashes occurring near the summit. Glacial moraines and drift cover the foreground and middle distance.*

(Geological Survey photograph (Crown copyright reserved).)

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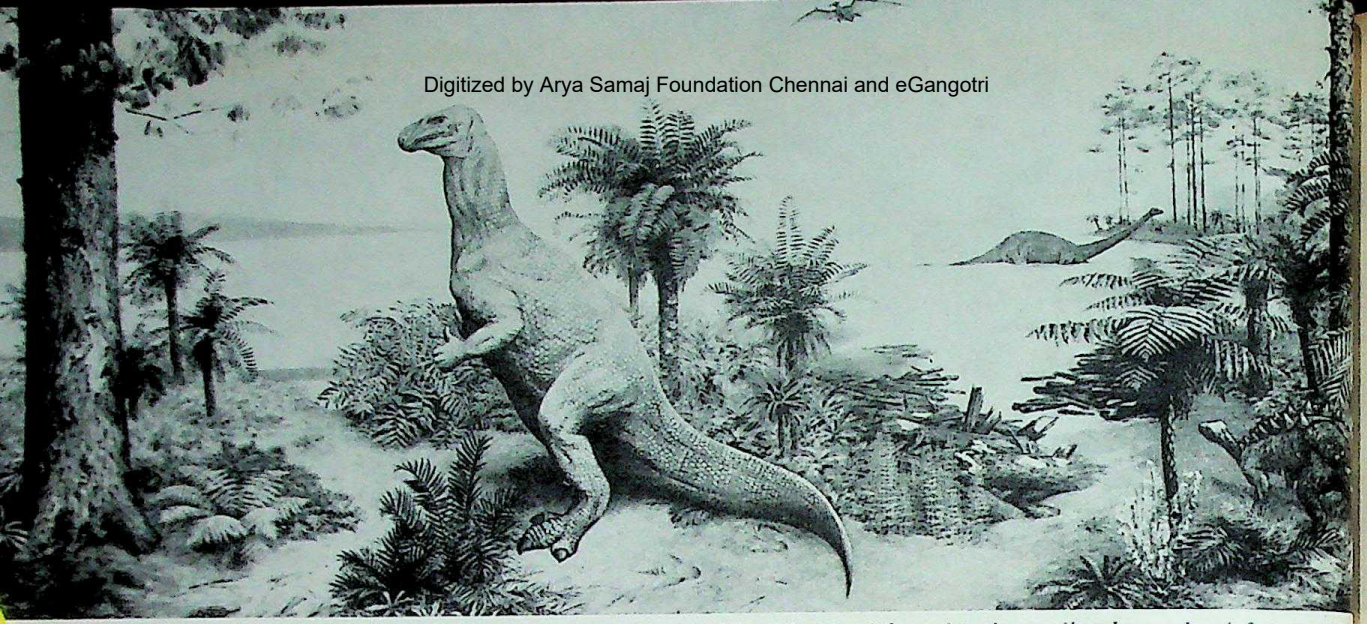

FIGURE 10 – *A Wealden landscape: restoration of the shores of the Wealden lake, with the reptiles Iguanodon (foreground), Brontosaurus (emerging in the background) and a Pterodactyl gliding overhead. Among the plants shown are conifers, cycads, and ferns.*
(From a diorama in the Geological Museum. Geological Survey photograph (Crown copyright reserved).)

FIGURE 11 – *Reconstruction of a typical Coal Measure forest scene, from a diorama in the Geological Museum, London.*
(Geological Survey photograph (Crown copyright reserved).)

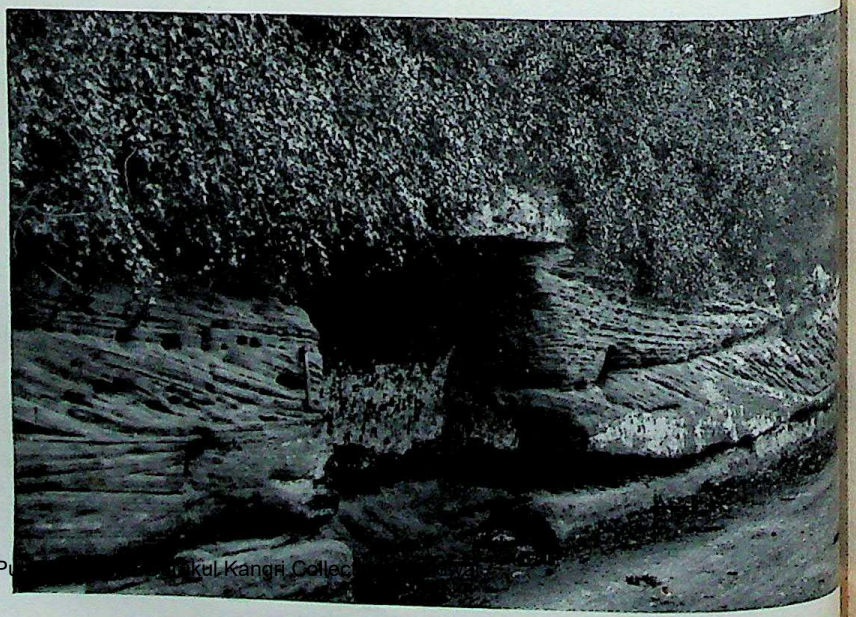

FIGURE 12 – *Road section showing dune-bedding in the Trias (New Red Sandstone) at Brimstree Hill, Salop.*
(Geological Survey photograph (Crown copyright reserved).)

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were probably then, as now, dry land and formed the northern margin of a narrow isthmus or elongated peninsula which separated the main Welsh trough of deposition from a northern sea in which were laid down the peculiar calcareous Cambro-Ordovician rocks of the north-west Highlands with their strongly American affinities. In Cambrian times, the southern shore of this land barrier was perhaps in the region of Anglesey, trending approximately north-east, while open sea dotted with islands extended eastwards towards the Baltic. Pre-Cambrian rocks in Shropshire, the Malverns, the Lickey Hills, Charnwood, and probably those regions near Northampton, Bletchley, and the Norfolk coast, where deep bores have revealed pre-Cambrian rocks immediately beneath the Mesozoic, must all have been islands projecting out of the Cambrian sea. They form a broad east-west belt, but are probably the peaks of a complex system of low ridges trending more north-south or north-west–south-east.

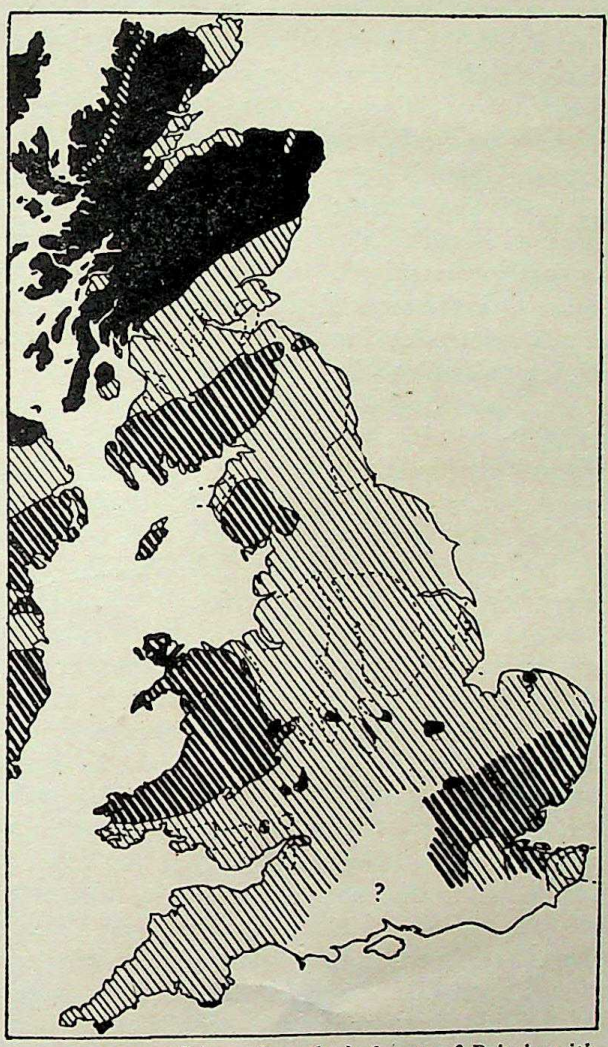

FIGURE 13 – *Schematic geological map of Britain with the cover of Tertiary and Mesozoic rocks removed. The absence of Upper Palaeozoic rocks over much of the south-east area is no doubt due largely to post-Carboniferous uplift and erosion; but there are some areas where even Upper Carboniferous rocks were never deposited and snags of pre-Cambrian and Lower Palaeozoic rocks representing a rugged island belt extending eastwards across the Midlands are shown projecting through the Upper Palaeozoic. Shading as in figure 1.*

In the succeeding Ordovician period, the shoreline of the main Welsh trough moved away to the north-west, submerging the Lake District and the Southern Uplands of Scotland. We then have evidence of a roughly parallel shoreline to the south-east—the coast of a southern land-mass occupying eastern England and the Midlands, where the Ordovician was never deposited. There is no indication of sediments later than the Lower Ordovician in the north-west Highlands, and no further evidence of that northern sea; but the fossil faunas of the Southern Uplands region sometimes suggest American affinities in the later Ordovician. The Ordovician period is noteworthy for its volcanic activity, submarine volcanoes in North Wales and the Lake District ejecting great thicknesses of lava and volcanic ashes (figure 9).

In Silurian times, while the northern shoreline remained approximately unchanged across central Scotland, the sea spread again south-eastwards, submerging first the coastal zone of the eastern land-mass, and finally the whole of eastern England as in Cambrian times. Late Silurian sediments are shallow-water in character, with occasional indications of brackish deposition, bringing to a close the great Lower Palaeozoic marine phase.

During this phase, sediments in the deeper part of the trough had attained an aggregate thickness computed at about nine miles, so that as the floor of the trough continued to sink and fresh sediment poured in, the earlier deposits were buried to a very considerable depth, and must have been subjected to high temperatures. While no true metamorphism (recrystallization) occurred, the subsequent compression as the trough was squeezed beneath its heavy overburden in places converted the Cambrian shales to perfect slates (as for instance in the North Wales slate belt) and even the Ordovician volcanic ashes of Wales and the Lake District assumed a rude cleavage across their original bedding planes. The most spectacular deformation attributed to these Caledonian movements occurs among the pre-Cambrian and Cambrian rocks in north-west Scotland, and the pre-Cambrian of the Grampians, though deformation

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of the latter may be of some pre-Cambrian age. In the former area, crystalline pre-Cambrian rocks have been carried forward for miles along almost horizontal fracture-planes or thrusts, to come to rest upon Cambrian sediments lying undisturbed and unaltered on the stationary pre-Cambrian block to the north-west (figure 6). In the Grampians, pre-Cambrian rocks have developed huge horizontally-lying folds before finally yielding to thrust displacement. Further south, the soft Lower Palaeozoic shales of the Southern Uplands have developed a steeply inclined concertina-folding; while in the Lake District and North Wales large-scale simple folds are sometimes associated with thrusting. Snowdon (figure 9) is the eroded remnant of a large, deceptively simple-looking basin or syncline of Ordovician volcanic rocks, lying between the Cambrian and pre-Cambrian rocks of the Menai region and the great Harlech Dome (Cambrian). The rugged scenery of the Lake District has been carved out of a great anticline of Ordovician slates and volcanic rocks.

A newly elevated land-surface, diversified by what must have been high mountain ranges over Wales, the Lake District, and Scotland, now occupied all Britain north of an almost east-west coastline passing through the Bristol Channel region. The Caledonian movements had welded Britain to a great northern continent, which may have extended so far as to include Scandinavia, Spitsbergen, and Greenland.

Between the main mountain ranges, huge outwash-fans of sediment (the Old Red Sandstone) accumulated in a semi-arid climate with torrential seasonal rains. True lake deposits are not much in evidence in the Lower or Upper Old Red Sandstone, but extensive waterlaid deposits of Middle Old Red Sandstone age are found in the Shetlands, Orkneys, and adjacent mainland, an area to which the name Lake Orcadie has been given. Altogether, but not all in one place, the succession of Old Red Sandstone sediments amounts to a thickness of 20,000 feet or more. Earth movement in the nature of readjustment continued well into Old Red Sandstone times; outpourings of lava characterize the Lower Old Red Sandstone of southern and central Scotland, and many of the northern granite intrusions are of this age. To the south lay the sea, in which were deposited the contemporaneous marine rocks of Devon and Cornwall, and, away to the east, the Ardennes and the Rhine provinces.

This land surface with its great pockets of Old Red Sandstone was by no means completely levelled by erosion before submergence allowed an irregular northward transgression of the sea, and England entered upon its second marine phase.

The Carboniferous is a vast system, representing a time interval of some 80 million years—half as long again as the whole of the Tertiary and perhaps two-thirds of the entire Mesozoic. Conditions of deposition and shorelines varied so greatly during this time that we cannot attempt to consider it as a single unit. Towards the end of Lower Carboniferous times, most of England was submerged; but a large part of Wales stood up as a sizable island perhaps extending to the Irish coast, and an archipelago of smaller islands stretched eastwards across the Midlands—an echo of those islands strung across the Midlands in the Lower Palaeozoic. Deltaic conditions existed in central Scotland at the mouths of great rivers draining the land further north, and irregularly-scattered islands lay offshore in the Southern Uplands, the Lake District and perhaps north-east Ireland. The overlying Millstone Grit is a complex deltaic deposit of grits and shales, interspersed rarely with marine shales marking repeated subsidence. This overspread most of the country and in turn gave place to the Coal Measure forest swamps (figure 11), spreading down from the north, alternating during periods of subsidence with sandstones, silts, and shales of freshwater, estuarine, and rarely marine origin. Finally, at the top of the Carboniferous strata, unproductive 'red measures' indicate the onset of arid conditions. The truly marine phase of the Carboniferous was of relatively short duration, but the peculiar deltaic and swamp conditions of the Middle and Upper Carboniferous accompanied long-continued subsidence, and their sediments accumulated to a great thickness. By the end of the Carboniferous period, subsidence and sedimentation together had probably swamped all but the peak areas of the Caledonian mountain system.

Now came the second great period of earth movement, the full force of which was felt more in north-west Europe than in Britain itself. The greatest effects here are seen in Devon and Cornwall, where slaty cleavage has been developed in Devonian shales; and the Bristol and South Wales coalfields show a more severe contortion than those of the north. Folding of the Coal Measures and underlying rocks was conditioned, particularly in the Midland area, by the submerged or semi-submerged ribs of hard pre-Cambrian and

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Lower Palaeozoic rocks beneath. To this period also is to be attributed the trough-faulting of the midland valley of Scotland, which has let down and preserved from erosion the Old Red Sandstone and Carboniferous rocks of industrial Scotland.

Again Britain was firmly incorporated in a northern land-mass, now lapped to the east of the Pennines by the margin of a great desiccating inland sea, centred over Germany, in which was deposited the Magnesian Limestone with its associated beds of marl, rock-salt, and gypsum. This series of strata rests upon a remarkably level surface planing the East Pennine coalfields. Elsewhere the surface shows a somewhat greater relief. Semi-arid and desert conditions prevailed over the low-lying areas between the upstanding masses to the west and north-west, and the Palaeozoic platform to the east where the New Red Sandstone accumulated. Rock-salt, gypsum, and red marls betoken the drying-up of small inland seas, and current-bedding of the sandstones (figure 12) proclaims wind action as surely as the polished surfaces of pre-Cambrian that project through the New Red Sandstone marls at Charnwood Forest.

Submergence of this land is reflected in the transition to marine deposits of the Jurassic, whose approximate eastern shoreline has already been indicated (figure 5 (*b*)). The western coast is more difficult to locate, for to that side lie the eroded edges of the present-day outcrops at surface; but there is reason to suppose that Wales and western England were mainly dry land. Nor did the sea extend very far to the north, for in this direction the Jurassic deposits become deltaic in character, providing a curious parallel to the conditions that existed in the Lower Carboniferous period. Further north, a narrow inlet, at times perhaps an estuary, seems to have followed round what is now the west coast of Scotland, and traces of the sediments deposited there are preserved under the cap of Tertiary lava.

The continuity of the Mesozoic marine phase was very nearly broken at the end of the Jurassic; uplift led to a narrowing of the sea, and eventually to the appearance of a land-bridge across the Midlands, separating a marine area to the north-east from a freshwater lake to the south-east and south. Thus all but a portion of south-east Lincolnshire had become dry land or freshwater swamp (figure 10). The marine transgression of the Cretaceous, after breaking through this land-barrier, carried the sea as far north-west as Antrim and the Western Isles. Whether Wales and the Lake District were submerged even then is open to doubt; but the Palaeozoic land-mass of south-east England vanished beneath the Chalk seas and has never since reappeared at surface.

The ensuing uplift revealed by the slight pre-Tertiary unconformity was of short duration in south-east England, which was soon submerged again beneath the shallow waters of an eastern sea. This sea stretched away to the east and south-east to include in the same general area of deposition the Tertiary rocks of the Paris basin, Belgium, and Holland (the Anglo-Parisian basin). To the north-west, early Tertiary volcanic action built up a great basaltic plateau, two or three thousand feet high, of which the remnants are today found in Northern Ireland and the Western Isles of Scotland (figure 7).

The Caledonian earth movements were severely felt in Britain; the Permo-Carboniferous movements less intensely; and still less the mid-Tertiary or Alpine movements, whose effects are practically confined to south-east England. Locally, along the Hog's Back, near Guildford, and in the Isle of Wight and in Purbeck, dips rise to verticality, but over most of the area the regional dip rarely exceeds two or three degrees. The London and Hampshire basins and the Weald anticline are large-scale but very shallow structures.

Erosion of the Weald anticline was rapid, for marine sands of Lower Pliocene age rest directly upon Chalk at places on the North and South Downs and the Chilterns. The uplift that followed left the whole of Britain dry land, except for the eastern edges of Norfolk and Suffolk, which received the marine shell-banks or 'crags' of the Upper Pliocene.

By then the present topography and outcrops had been virtually determined, save for relatively minor effects of the Quaternary era. Moving valley-glaciers left their characteristic modifications on upland topography; and vast ice-sheets blanketed lowland areas of all but southern England with deposits of boulder-clay and drifts. Diversion of drainage occurred here and there, through blocking of pre-Pleistocene valleys with ice or drift; and changes in sea level, due to loading and unloading of the land surface with ice, resulted in drowned valleys, submerged forests, and raised beaches around our coasts. To us, the most important of all Quaternary events was the break-through of the sea at the English Channel.

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The Royal Society of Edinburgh

JAMES KENDALL

The title of Fellow of the Royal Society of Edinburgh has long been recognized as a high academic honour. Among the many distinguished scientists who have been Fellows of the Society may be mentioned Joseph Black, Thomas Hope, James Hutton, Thomas Graham, Clerk Maxwell, Crum Brown, and Lord Kelvin. Literary genius has been represented by Goethe and Sir Walter Scott (President from 1820 till 1832). Professor Kendall here recounts the history of the Society, unbroken from its foundation in 1783 up to the present day.

The Royal Society of Edinburgh, like its senior sister the Royal Society of London, did not spring suddenly into existence; it gradually evolved from a series of less formal associations originating in a period of civil stress. The Philosophical College instituted in London during the struggle between King Charles I and Parliament in 1645, and continuing its sessions at Oxford during the Protectorate, had its northern counterpart, a century later, in the Philosophical Society of Edinburgh.

This Society itself was an amalgamation of two more specialized bodies—a Medical Society, founded in 1731, and a Society for improving Arts and Sciences, six years younger. Alexander Monro *primus*, the anatomist, was the secretary of the former; the six volumes of *Medical Essays and Observations* communicated to the Society and published under his supervision assisted significantly in spreading the fame of the Edinburgh Medical School throughout Europe. Colin Maclaurin, the mathematician, was the moving spirit of the latter, but his exertions in the attempted defence of Edinburgh against the Jacobite army in 1745 led to his untimely death and the temporary suspension of all its activities. When tranquillity was restored the two conjoined societies, with David Hume and Alexander Monro *secundus* as secretaries, settled down once more to serious business; three volumes of *Essays and Observations, Physical and Literary*, published between 1754 and 1771, contain contributions on a wide range of subjects by leaders in almost every field of science, philosophy, and letters.

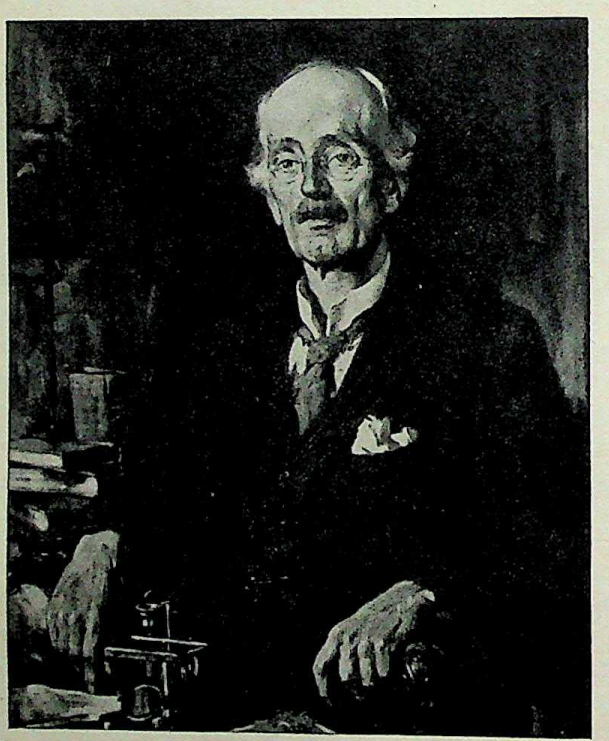

FIGURE 1 – *Sir William Wright Smith, Present President of the Society.*
(*From a painting by Stanley Cursiter, R.S.A., F.R.S.E.*)

In 1782, however, a new crisis arose. Lord Buchan's petition for a charter for the Society of Antiquaries of Scotland was opposed by the University, at the instigation of its principal, William Robertson, who preferred one comprehensive learned society; and this opposition, vain though it proved, was the immediate cause of the formation of the Royal Society of Edinburgh. Writing to a friend on 30th November, 1782, Andrew Dalziel, Professor of Greek, remarked:

> Lord Buchan is kicking up a sad dust about his Antiquarian Society. He has admitted such a number of ragamuffins that the respectable members are resigning very fast, and joining the University and Faculty of Advocates in an application for a Royal Charter for a new Society.

Robertson's scheme, as finally adopted at a meeting of the professors of the University, many of whom were members of the Philosophical Society, called indeed for 'the establishment of a New Society on a more extended plan, and after

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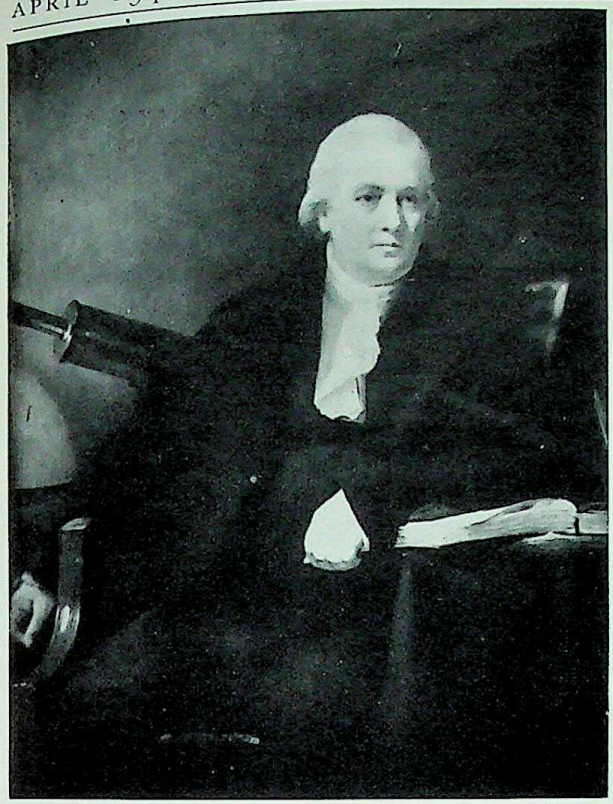

FIGURE 2 – *John Robison, General Secretary* 1783–98.
(From a painting by Sir Henry Raeburn, F.R.S.E.)

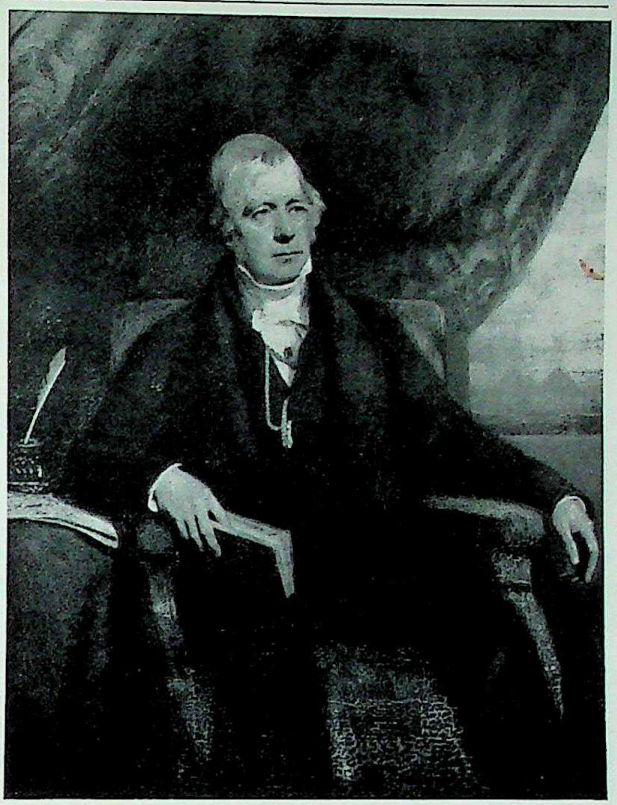

FIGURE 3 – *Sir Walter Scott, President* 1820–32.
(From a painting by J. Graham-Gilbert.)

the model of some of the foreign Academies, which have for their object the cultivation of every branch of science, erudition, and taste.' The patronage of the King was solicited, and a Charter of Incorporation was granted by King George III in March 1783.

The first meeting of the Royal Society of Edinburgh was held on 23rd June of the same year, in the University Library, with Principal Robertson in the chair. It was resolved that all members of the Philosophical Society should be assumed as Fellows of the Royal Society. The Duke of Buccleuch was elected president, and John Robison secretary. Buccleuch's appointment was essentially titular, although he did contribute to the first volume of the Society's *Transactions* an extensive record of the weather and the rainfall at his various country seats. Robison, on the other hand, the Professor of Natural Philosophy at the University of Edinburgh, was an 'Admirable Crichton' type of scientist, who had previously occupied the chair of chemistry at Glasgow, in succession to Joseph Black, and the chair of mathematics at the Naval College, Kronstadt. As a young man, he was in the same boat with Wolfe before the capture of Quebec, and recorded the doomed general's recital of Gray's *Elegy* during the journey up the St. Lawrence to the Heights of Abraham. His portrait by Raeburn, presented by his son Sir John Robison, a subsequent secretary, is probably the most valuable possession of the Society today.

The Fellows, as also the published *Transactions* of the Society, were originally divided into two classes—physical and literary—but it soon became obvious that the scientific side was to be predominant. Very few literary papers were submitted, and separate meetings of this class soon ceased to be held. Only one literary president of the Society was ever appointed, namely Sir Walter Scott, who held office from 1820 to 1832. His portrait, by Graham-Gilbert, also hangs in the Society's rooms. He was, for a long time, most conscientious in his attendance at all functions; Charles Darwin mentions in his *Autobiography* that he went to a meeting of the Society in 1827, when he was a medical student at Edinburgh, and saw Walter Scott in the chair.

The scientific publications of the Society immediately took their place in the front rank. In the very first volume of the *Transactions*, James Hutton began a geological conflagration which blazed

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fiercely throughout Europe for many years afterwards by a communication on his Theory of the Earth, over which the Neptunists and the Vulcanists fought with much fury. His main principles were ultimately generally accepted, and he is regarded as the father of physical geology. Sir James Hall, the second president of the Society, tested and confirmed Hutton's conclusions by direct experiment, and may be called the father of experimental geology. In chemistry, Joseph Black sang only his swan-song in a routine analysis of the waters of some hot springs in Iceland, but his pupil and colleague Thomas Hope added a new element to knowledge in his 'Account of a Mineral from Strontian, and of a peculiar Species of Earth which it contains.' In Vol. XII, Thomas Graham published his celebrated 'Memoir on the Law of Diffusion of Gases.' Other branches of science were equally well represented, but it is a pity that Adam Smith, a Charter Fellow, did not add to the *Wealth of Nations* by any contribution to the Society's publications.

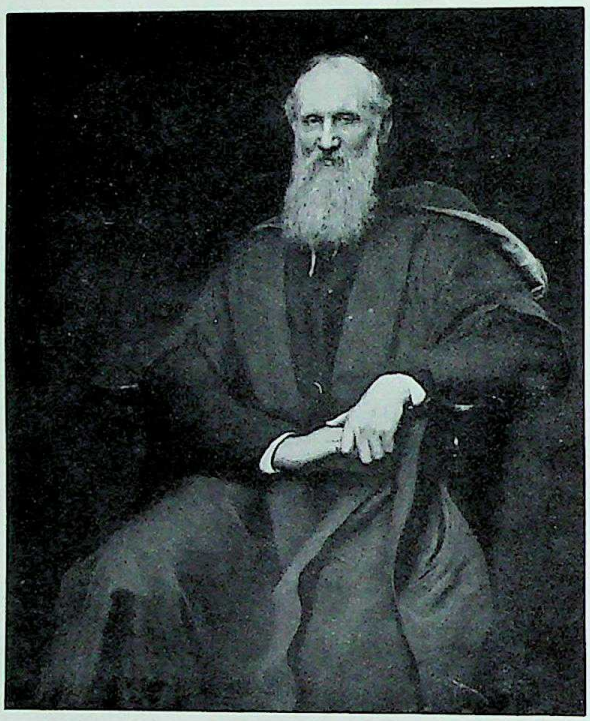

FIGURE 4 – *Lord Kelvin*, *President* 1873–78, 1886–90, 1895–1907.
(From the Herkomer portrait in Glasgow University.)

From its foundation the Society exercised the right of electing a limited number of foreign Honorary Fellows; Benjamin Franklin was among the first to be so distinguished. Most of the leaders in scientific progress in all parts of the world during the past 150 years have found a place on the list, but the only name which calls for particular mention here is that of J. Wolfgang Goethe. Goethe was very appropriately elected during the presidency of Sir Walter Scott, and it is interesting to note that he received the honour for his distinction in science as well as in literature. Goethe himself was of the opinion that his poetry would be forgotten but that his work on light and colour would live. Time has proved the opposite.

As science expanded during the nineteenth century, it became necessary to divide the publications of the Society into *Proceedings* and *Transactions*, and recently the *Proceedings* themselves have been subdivided into two sections—Physical and Biological. The total mass of work published in the sixty-two volumes of *Proceedings* and sixty-one volumes of *Transactions* is too immense to admit of any analysis here; a few items of exceptional character do, nevertheless, deserve brief comment.

In 1846, for instance, Clerk Maxwell, then a boy of fifteen at the Edinburgh Academy, wrote his first paper for the Society on the 'Properties of certain Oval Curves' — the manuscript is still preserved. His teacher, Forbes, however, had to read both this communication and another submitted a year later on Rolling Curves or Roulettes, for it was not considered proper for a boy in a round jacket to address the Society! Could it have been foreseen that this boy was destined to become the greatest mathematical physicist of the century, a different decision might have been given.

In 1873, a youth not many years older than Clerk Maxwell *was* permitted to read a paper, a dreary article 'On the Thermal Influence of Forests.' Perhaps he was favoured by the fact that his father was a prominent Fellow of the Society—eleven years later, indeed, its president. A typical sentence from this communication runs as follows:

> A wood, then, may be regarded either as a *superficies* or as a *solid*; that is, either as a part of the earth's surface slightly elevated above the rest, or as a diffused and heterogeneous body displacing a certain portion of free and mobile atmosphere.

This is not nearly as exciting as *Treasure Island* or *Kidnapped*, but its author was no other than Robert Louis Stevenson!

The latter half of last century was a golden age for the Society under the able guidance of the famous firm 'T and T'—Sir William Thomson (Lord Kelvin) and Peter Guthrie Tait. Kelvin

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was president for three terms, twenty-one years in all; Tait was Secretary to Ordinary Meetings and General Secretary for a total period of thirty-seven years. Many of Kelvin's research papers and nearly all of Tait's are included in the Society's publications. Crum Brown in chemistry and Chrystal in mathematics were other giants of this era.

Towards the close of his final term of office, Kelvin saw the Society safely through a critical domestic upheaval. For more than eighty years it had occupied a suite of rooms in the Royal Institution, the monumental building facing Princes Street at the foot of the Mound. In 1906, however, the Secretary for Scotland introduced into the House of Commons a bill providing that the Royal Institution should become a National Gallery and be applied to the promotion of the Fine Arts. Faced with compulsory removal, an influential deputation of Fellows, headed by Kelvin, urged upon the Government the claims of the Society for State support in obtaining adequate alternative accommodation for its meetings, its valuable library, pictures, and manuscripts, and the transaction of its general business. A clause was inserted into the bill by which the requisite funds were assured, and in 1909 the new home of the Society in George Street was opened by Sir William Turner, Kelvin's successor in the presidential chair.

The premises provided appeared commodious then, but they are congested now. Inordinate expansion of the membership of the Society has been checked by limitation of new Fellows to twenty-five annually—a move which will certainly enhance the high prestige that has always attached to the letters F.R.S.E.—nevertheless the attendance at most of the regular monthly meetings overcrowds the reception rooms, and even standing space in the lecture theatre is frequently at a premium. More serious still is the library situation; the Society participates in more than 600 exchanges over the whole world, and its collection of scientific periodical literature and works of reference is one of the most complete in the British Empire; but the saturation point for stacking new volumes is already exceeded, and the official Curator will be faced with an insoluble problem when war-time arrears are re-established. Facilities for the exhibition of the Society's manuscripts are also most urgently needed.

The Society has in its award a number of prizes. The Keith and Makdougall-Brisbane Prizes are both given biennially, in the physical and biological sciences alternately, for the best communication to the Society's publications during the period immediately preceding. The Neill Prize is also awarded biennially for a paper of distinguished merit, on some branch of natural history, by a Scottish naturalist. The Gunning Victoria Jubilee Prize is awarded quadrennially in recognition of original work in physics, chemistry, or pure or applied mathematics, and is open to men of science resident in or connected with Scotland. The James Scott Prize is offered triennially for a lecture or essay on the fundamental concepts of natural philosophy, and the Bruce Prize biennially for some notable contribution to natural sciences, 'the outcome of a personal visit to polar regions on the part of the recipient.' In addition, the Bruce-Preller Lecture Fund affords biennially an honorarium for an address by an outstanding man of science in geology or electrical or physical science, and the David Anderson-Berry Fund a triennial medal and prize for an essay on X-rays and their therapeutical effect. Finally, under a recent bequest by the late Mr Robert Cormack, the Society has been directed to administer the residue of his estate, approximately £54,000, for the purpose of promoting astronomical knowledge and research in Scotland.

To end on a less monotonous note, mention may be made of a Dining Club of the Society, founded in 1820. Its functions are explained by Sir Walter Scott as follows:

> It is a very good institution; we pay two guineas only for six dinners in the year, present or absent. Dine at five, or rather half-past five, at the Royal Hotel, where we have an excellent dinner till half-past seven, then coffee, and we go to the Society. This has great influence in keeping up the attendance, it being found that this preface of a good dinner, to be paid for whether you partake or not, brings out many a philosopher who might not otherwise have attended.

When the length of the repast, at which 'mulled wine and punch were manufactured and consumed according to the latest philosophical discoveries,' is borne in mind, it is not surprising to learn that Scott, on 4th December, 1826, 'listened without understanding a single word, to two scientific papers; one about the tail of a comet, and the other about a chucky-stane.' To avoid such lapses nowadays, the dinners are held *after* the ordinary scientific sessions. During the war, of course, all convivial activities were suspended, but the 599th meeting of the Club—a Victory celebration—was held with moderated austerity on 3rd December, 1945.

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Mineral deficiencies in plants

T. WALLACE

Few scientific discoveries have had greater economic and social effects than the recognition of the importance of minerals in plant nutrition. From it has arisen one of the most important branches of chemical industry, the production of fertilizers. Professor Wallace here discusses problems relating to the diagnosis, cause, and cure of mineral deficiencies in the field, proper understanding of which is necessary to the most effective use of fertilizers.

Little more than a century has elapsed since Liebig, in 1840, first advanced his theory of the mineral nutrition of plants. Subsequent practical experience and scientific investigations have fully confirmed the importance of minerals in crop production, and various aspects of mineral nutrition of plants have been closely investigated. Particular attention has been paid to the identification of the elements essential for the growth of plants, and to the effect on various growth processes of the omission of one or more of these elements from the nutrient medium. Since crop plants satisfy a considerable part of the mineral requirements of cattle, an important aspect of recent research has been the investigation of the relationship between the mineral deficiencies of plants and the health of stock feeding on them [1].

Experimental methods used in problems of plant nutrition have been of three main kinds. There have been extensive trials of crops under field conditions, carefully controlled experiments using pot or water culture methods, and, finally, elaborate experiments in the laboratory using highly refined methods of chemistry and plant physiology. The elements concerned with the growth of plants fall into three groups: the *essential major elements*—nitrogen, phosphorus, calcium, magnesium, potassium, and sulphur—which are required in relatively large amounts; the *essential trace elements*—iron, manganese, boron, copper, zinc, and molybdenum—which are equally indispensable but are required in only very small quantities; and four elements—sodium, chlorine, silicon, and possibly aluminium—which, although perhaps not absolutely essential, are definitely beneficial for certain plants.

Deficiency of any of these elements may be of an absolute or a relative kind. It may arise directly from an acute shortage of the particular element in the soil, or from a relative shortage induced or accentuated by an excess of some other element. Thus a deficiency of potassium may arise from excess of nitrogen or phosphorus. Deficiencies of the trace elements iron and manganese are largely determined by the *p*H of the nutrient medium, these two elements being less readily utilized by plants at high *p*H values; boron deficiency too is often induced by liming. On the other hand, the molybdenum content of the herbage of 'teart', i.e. scouring, pastures assumes proportions toxic to animals when the *p*H of the soil is high. Finally, it must be emphasized that mineral deficiencies are related to the general plant environment: in particular to conditions of the atmosphere and soil, such as light intensity, temperature, and moisture content.

From the point of view of practical agriculture, important aspects of mineral deficiency investigations are (*a*) those relating to the effects on the various crop plants of specific deficiencies, (*b*) methods of detecting the exact nature of any deficiency, and (*c*) the practical means of correction under field conditions. In many crops, symptoms of specific deficiencies are so characteristic that they can be recognized by visual inspection, and this has made possible the method of visual diagnosis which has proved of great practical value. Where the visual method cannot be applied or requires confirmation, other quick tests, including chemical, spraying, and injection techniques are used [2].

Nitrogen deficiency leads to a general stunting and sparsity of growth. The leaves of affected plants are generally pale and tend to assume bright yellow, red, or purple tints. Blossoming, seed formation, and fruiting are much reduced. The effects of *phosphorus* deficiency are in many respects similar to those of nitrogen deficiency, but the leaf tints are often dull purple or the foliage may merely lack lustre and appear dull green. Leaf margins may look scorched, as in potatoes, or spots may develop over the whole leaf, as in

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FIGURE 1 – Rape Plant. *Calcium deficiency. Leaf margins and mesophyll wilt and collapse.*

FIGURE 2 – Cauliflower Plant. *Manganese toxicity developed under conditions of calcium deficiency. Manganese toxicity shows as curling and spotting of leaf margins, and calcium deficiency as necrosis of the mesophyll. These conditions may develop together in plants on strongly acid soils.*

clovers and black currants. Symptoms of *calcium* deficiency first appear near growing points and in roots. Leaves become distorted, rudimentary, rolled, and scorched; roots are often stumpy; tuber formation, as in potatoes, is greatly restricted. Soil acidity, which accompanies calcium deficiency in the field, may induce manganese toxicity effects, such as chlorosis and leaf rolling, as secondary symptoms (figure 2). *Magnesium* deficiency particularly affects the foliage. Chlorosis is common but brilliant tints are also frequent; leaves are shed prematurely, often without previous withering. Despite the severity of leaf symptoms and extensive defoliation, the effect on crop yields may not be serious. The symptoms of *potassium* deficiency vary with its severity. Slight deficiency restricts the growth of shoots whilst severe deficiency may cause them to 'die back.' Growth generally appears squat, because of short internodes, and flowering stems may fail to develop. Leaf symptoms are generally characteristic and usually include marginal scorching, tip burn, or spotting; and intervenal chlorosis may occur. The laminae may be rolled forward parallel with the midrib or may be gently curved back. Grain and fruits are generally small and of poor quality. *Sodium* deficiency is seen only in sodium-loving crops such as sugar beet and mangolds. Leaves are dark green, lack lustre, and wilt rapidly in drought. *Sulphur* deficiency has not been reported in Great Britain. When it is deliberately induced in plants, the symptoms somewhat resemble those of nitrogen deficiency.

Lack of *iron* is characterized by severe chlorosis of the tip leaves of young growths; this is generally followed by 'die back' of the shoots. The leaves may be entirely bleached, or chlorosis may take the form of mottling, as in *Brassicae*, or intervenal stripes, as in cereals. In *manganese* deficiency too, leaf symptoms are generally notable. Chlorosis, similar to that due to lack of iron, is common, but many plants show other characteristic symptoms. In oats, for example, the condition known as 'grey speck' appears. Chlorosis generally follows a well-defined pattern but, unlike that associated with iron deficiency, is not most severe on the leaves at the tips of shoots. Peas, and occasionally various types of beans, develop circular brown lesions on the flat surfaces of the cotyledons in the seeds (Marsh Spot) (figure 12).

The symptoms of *boron* deficiency [3] are generally so characteristic that for many plants they have been assigned definite descriptive names, such as 'Crown Rot' of sugar-beet and mangolds,

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FIGURE 3 – Barley Plants. *Potassium deficiency. Leaves are semi-chlorotic and show irregular white lesions.*

FIGURE 4 – Mangold Plant. *Potassium deficiency. Leaves show marginal and intervenal scorching. The older leaves are affected first, wither prematurely, and fall to the ground.*

FIGURE 5 – Potato Shoot. *Calcium deficiency. Shoots are much branched and young leaves are very small with margins folded towards their upper surfaces.*

FIGURE 6 – Apple Shoots. *Iron deficiency. The leaves develop chlorosis and later some marginal scorchi Severely affected shoots eventually die back.*

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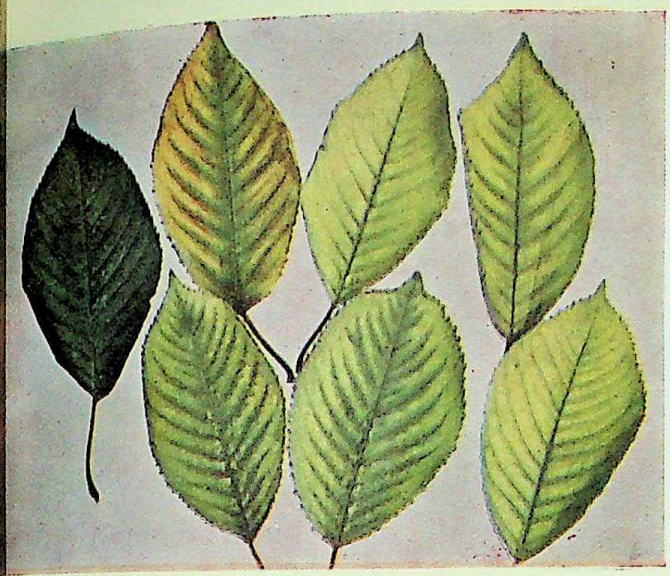

FIGURE 7 – Sweet Cherry Leaves. *Manganese deficiency. Leaf margins become chlorotic and the chlorosis spreads intervenally as a V-shaped pattern towards the midrib. The whole lamina may eventually be affected.*

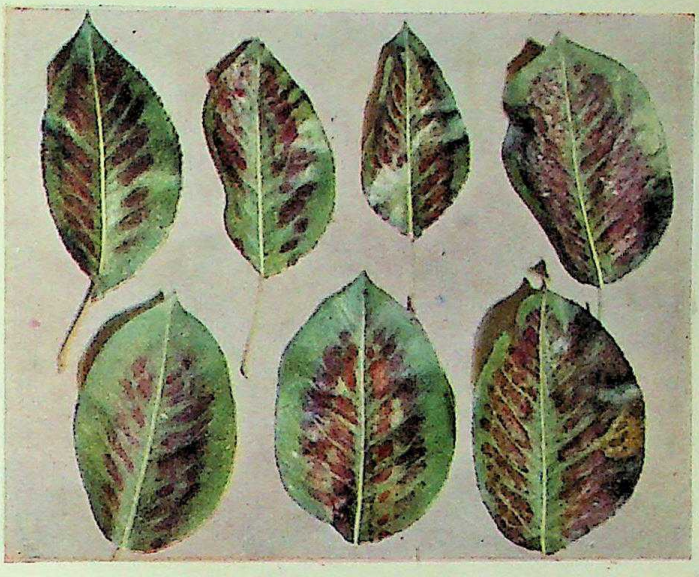

FIGURE 8 – Pear Leaves. *Magnesium deficiency. Intervenal areas around the midrib become necrotic.*

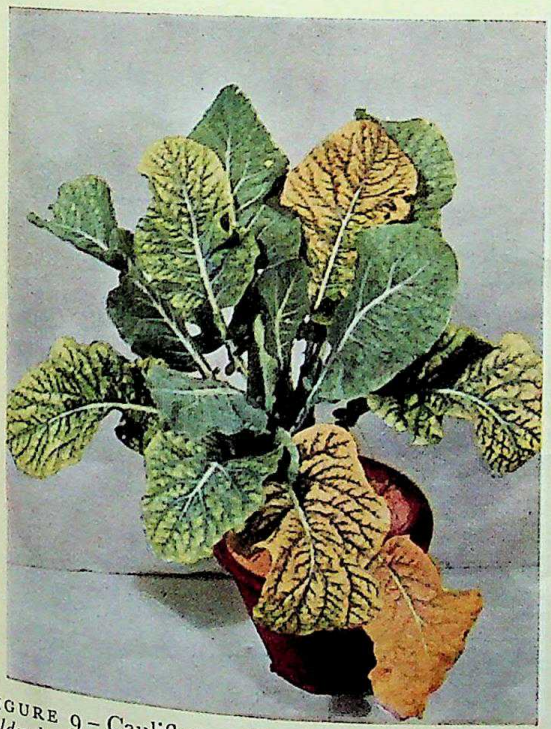

FIGURE 9 – Cauliflower Plant. *Magnesium deficiency. Older leaves show chlorotic 'marbling' and may also develop red and purple tinting.*

FIGURE 10 – Tomato Foliage and Fruits. *Magnesium deficiency. The foliage, beginning with older leaves and progressing to the younger, becomes chlorotic and later brown necrotic areas are developed intervenally.*

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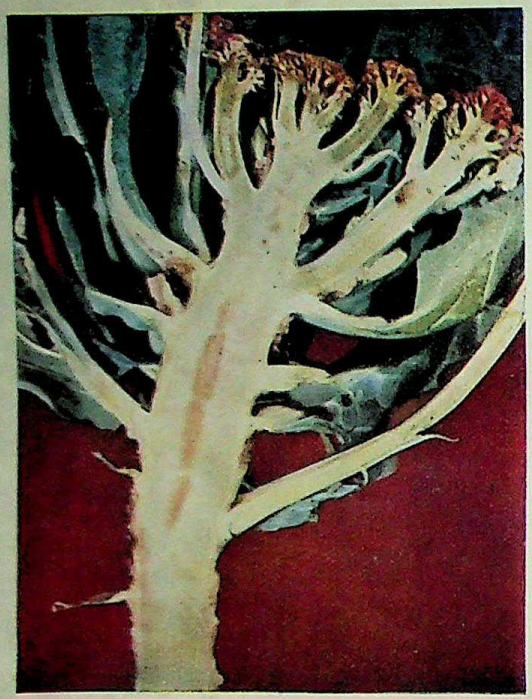

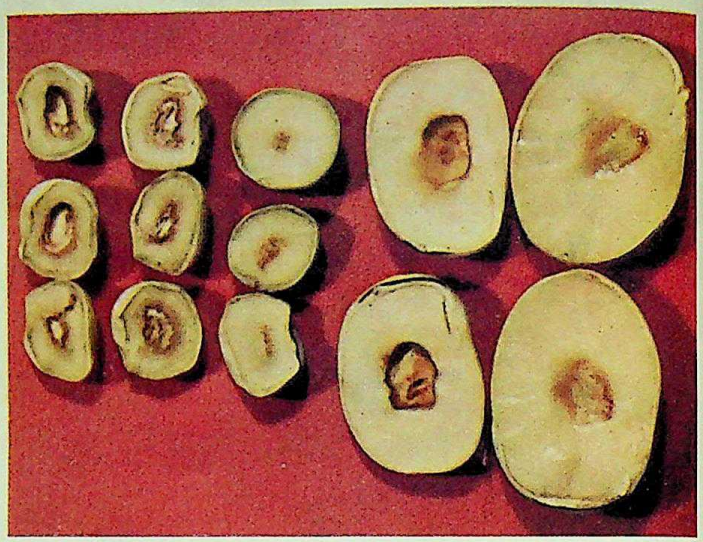

FIGURE 11 – Longitudinal Section through Cauliflower Head. *Boron deficiency. The curd is brown and the pith of the main stem shows brown lesions.*

FIGURE 12 – Pea and Broad Bean Seeds. *Manganese deficiency. The cotyledons show brown lesions in their centres.* (*In peas the condition is termed 'Marsh Spot.'*)

'Canker' of table beet, 'Brown Heart' or 'Raan' of swedes and turnips, 'Hollow Stem' or 'Browning' of cauliflowers, and many others. Growing points are generally so seriously affected that they die; the pith and epidermis of stems are damaged, giving rise to characteristic hollow and roughened stalks; leaves often show marginal scorching, mottling, and pigment formation, besides being cracked and wrinkled; fruits become dwarfed and malformed, and often develop internal necrosis.

Although deficiencies of *zinc*, *copper*, and *molybdenum* are important in many crops abroad, they have not been recorded in any field crop in Great Britain. Zinc deficiency is the cause of serious diseases in many fruit trees such as Citrus, apples, pecans, vines, and stone fruits [4]. 'Bronzing' of tung and 'White Tip' of maize result from lack of zinc, which is also responsible for poor yields of cereals from certain Australian soils. Deficiency of copper [5] causes serious pathological conditions in fruit trees, notably *Exanthema* of Citrus, etc. In Holland and Denmark it affects cereals, and is known as 'Reclamation Disease.' Australian cereal crops also are known to be affected. Molybdenum deficiency has been noted only in pasture plants and peas on certain ironstone soils in South Australia and Tasmania [6] [7]. Piper states that when the condition is deliberately induced in oats grown in water culture the following symptoms appear: necrosis occurs in upper leaves; the collapsed tissue dries and assumes a reddish brown colour; grain often fails to form.

This account of the visible symptoms of various types of mineral deficiency has been given in sufficient detail to illustrate the variety of the effects observed, permitting of differential diagnosis, and to emphasize the fact that their distribution and effects are such as to result in considerable losses in many crops.

Having described the effects of the various deficiencies, it is of interest to consider their distribution in relation to soils, and the methods of restoring the proper mineral balance when any particular deficiency occurs.

Deficiency of nitrogen may occur on any class of soil, and its occurrence is greatly influenced by the way in which the soil is managed and cropped. Thus supplies of soil nitrogen tend to increase under grass or leguminous crops and are decreased by arable cropping. A temporary deficiency may be induced if organic matter is ploughed-in in which the nitrogen–carbohydrate ratio is low. Provided other conditions are favourable for growth, the deficiency is easily remedied by the

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application of nitrogenous fertilizers. The response is generally quick and spectacular, since nitrogen is very mobile in most soils, and the effects are so well known that details are unnecessary.

In Great Britain, phosphorus deficiency is most prevalent in the north and west, districts of high rainfall. Soils differ considerably in their natural supplies of phosphorus, and many clay soils—for example those of the Lower Lias—are particularly deficient. Strongly acid soils, ironstone soils, and soils derived from the chalk formations and Fen peats, are also generally lacking in phosphorus. A wide range of materials is available for supplying this element. If the deficiency is acute, it is generally best to use a soluble fertilizer, such as superphosphate, and, to be most effective, the dressing must be applied at an early stage in the growth cycle. Certain soils, notably ferruginous, strongly acid, calcareous, and clay soils, present special difficulties owing to their capacity for rendering phosphates insoluble and thus unavailable to the plants. Various devices have been suggested for overcoming this problem. One is the use of granular fertilizers, which present a relatively small surface to the soil: alternatively the fertilizer may be drilled with the seed so that close contact is ensured. A third method, devised for plants such as fruit trees, whose roots are deep, is to force the fertilizer into the soil with special lances.

Calcium deficiency is confined to acid soils, and is also most prevalent in districts of high rainfall owing to the ease with which calcium is leached from the soil. The occurrence of calcium deficiency is often associated with a low calcium content of the parent rocks from which the soils are derived. In the field it is difficult to distinguish the symptoms of this deficiency from those due to other effects resulting from the accompanying acidity of the soil. Although neutral calcium salts may be helpful in relieving a condition of calcium deficiency, they are no substitute for lime, which is the usual practical remedy, because of its property of neutralizing the accompanying acidity. With root crops, such as sugar-beet and mangolds, it is usually advisable on strongly acid soils to plough in some of the lime as well as to apply a top dressing, since otherwise the tendency is for the roots not to penetrate into the subsoil but to become fangy or to turn horizontally at a shallow depth.

Magnesium deficiency is most likely to occur on acid soils also lacking in calcium. It may also be induced by excess of potash and is accentuated by low nitrogen status. Control is obtained by dressings of magnesian limestone or magnesium sulphate. The former is preferable on acid soils, as it neutralizes soil acidity, but it frequently cannot be used on soils of high *p*H as, by further increasing the *p*H, deficiencies of iron or manganese may be induced. When magnesium deficiency results from excessive applications of potash, it may be necessary to discontinue the use of the latter, even for crops such as tomatoes, until the unfavourable magnesium balance is restored. With certain crops, such as glasshouse tomatoes and fruit trees, soil dressings of magnesium materials have proved very slow in action, and for the former crop much quicker results have been obtained by spraying the foliage with magnesium sulphate (2 per cent. magnesium sulphate, as the heptahydrate, plus spreader) [8].

Potassium deficiency occurs most frequently on light soils, but it may occur on soils of any texture when potash-loving crops are grown. In Great Britain, the deficiency is most prevalent in the area approximating to the great Chalk Belt which stretches from Dorset to Yorkshire. The condition is readily brought about by taking frequent hay crops, and is of common occurrence in freshly ploughed old grassland. It is best controlled by dressings of potassium fertilizers such as the sulphate, chloride, and nitrate, or kainit. A variety of waste materials containing soluble forms of potash may also be used; dung is a good source. Like phosphorus, potassium is fixed to a greater or lesser extent in all soils, and its action may therefore be comparatively slow. This is particularly so with fruit crops, where two or three seasons of treatment may be required to remedy the deficiency.

Low concentrations of sodium, and also of chlorine, are found most frequently in Great Britain on sandy soils remote from the sea. The most suitable method of correcting both deficiencies is by application of agricultural salt.

As already mentioned, sulphur deficiency is unknown in Great Britain, possibly because of the variety of materials containing it which are normally added to the soil. When it does occur, the remedy is treatment with any of the usual sulphate-containing fertilizers. Elementary sulphur can also be used, as this is readily converted into sulphate by micro-organisms in the soil.

A high *p*H of the soil, and possibly also a high phosphorus content, are probably the most important factors in inducing iron deficiency. The effect of a high *p*H is to render iron unavailable to

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the plant, and it is generally impracticable to remedy the deficiency by adding iron salts to the soil. One method of treatment is to spray the foliage with a dilute solution (approximately 0·5 per cent.) of ferrous sulphate. In the case of trees, ferrous sulphate, ferric citrate, or ferric tartrate may be injected into the trunks and branches. The presence of actively decomposing organic matter or a grass cover tends to increase the availability of iron, and appreciable control can therefore sometimes be effected by incorporating dung into the soil or by growing a grass cover over the soil when trees are affected. The deficiency cannot usually be controlled satisfactorily in ground crops, but a method has recently been described for tomatoes, consisting of a peat mulch which is 'watered' with a solution of ferrous sulphate. The methods of treating iron deficiency cannot be said to be satisfactory, and it is the most difficult deficiency to treat in the field.

Manganese deficiency in England is associated with well-defined soil conditions. The most extensive areas occur in the Fens, Romney and Walland Marshes in Kent, and parts of Yorkshire. The special soil conditions usually present are a high *p*H (above 6·5), generally due to a high lime content, high content of organic matter, and imperfect drainage. During the war the trouble was especially marked on susceptible soil types when first crops were grown after breaking up old swards. The problems of controlling the deficiency are similar to those of iron, but the practical results of treatment are more satisfactory. Applications of manganese sulphate to the soil may be effective, but on some soils the results are disappointing. Soil treatment is ineffective for fruit trees, but control by spraying is practised with great success both on agricultural crops and with fruit trees. Effects due to overliming have been successfully overcome by application of sulphur, at the rate of about 1 ton per acre, but the treatment is too expensive. Sulphur thus applied lowers the *p*H of the soil. Good quality dung is effective in the season of application; basic slag may produce some benefits but has the disadvantage of further raising the *p*H of the soil.

Boron deficiency is probably determined mainly by the natural supplies of the element in the soil. It is most prevalent on light sandy soils and on those derived from chalk formations. It is often induced on sandy soils by liming. It is readily controlled by applications of borax or boric acid to the soil. In fruit trees it may also be controlled by stem injections or spraying with borax solution.

As zinc and copper deficiencies have not been recorded in Great Britain the corresponding soil conditions have not been determined here. The soil factors governing their occurrence are not understood, but low availability of zinc is thought to be related to the activities of the soil organisms and is induced by high concentrations of phosphorus. Copper deficiency is most prevalent on peaty soils but occurs also on sandy soils. Both deficiencies can be made good by application of the respective sulphates to the soil, or by foliage sprays or stem injections similar to those used for manganese.

The only recorded instances of molybdenum deficiency are in pasture plants and peas on ironstone soils in Australia and Tasmania. In 'teart' pastures, when molybdenum is present in toxic amounts in the herbage, the availability is increased if the *p*H rises. Deficiency has been controlled by application of ammonium or sodium molybdates, roasted molybdenite, or wood ashes. The available evidence suggests that less than 1 lb. of sodium molybdate per acre may be sufficient to prevent deficiency.

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Paludrine—a new antimalarial drug

FRANK L. ROSE

The capture of the East Indian quinine plantations by the Japanese, at a time when it was necessary to maintain large armies in some of the world's worst malarial regions, threatened to be a most serious blow to the Allied Nations. Fortunately the danger was overcome by manufacturing the synthetic drug, mepacrine, on a large scale. Although mepacrine proved very satisfactory, an intensive search was made in Great Britain for new and better anti-malarials and this work recently resulted in the discovery and development of paludrine.

Malaria is one of the major scourges of mankind. Even at the present time it attacks several hundred millions of people annually, and it is estimated that each year some three million die from the disease. It is impossible to compute how many more have their vitality so impaired that they fall an easy prey to other fatal diseases. In the past, malaria has wiped out entire populations, prevented colonization, and checked invading armies. Indeed, it is not an overstatement to claim for malaria a determining role in the history of the world. Nor does malaria occur only in the tropics. In former days it was rampant in Britain, when it was referred to as the ague, the malady from which Oliver Cromwell is said to have died. Even now it prevails in temperate zones as the tertian form, and the main tropical form (malignant subtertian) is to be found in the southern United States of America during certain seasons of the year. It is common knowledge that the disease is conveyed from man to man by an insect vector, the anopheles mosquito, but it is less well known that the causative parasites undergo a complicated life-cycle, some phases of which have not yet been fully elucidated. This article is concerned mainly with the chemistry of antimalarial drugs, but without a short account of some features of this life-cycle, it is not possible to indicate the full significance of the discoveries here described.

The word life-cycle denies a beginning for the existence of the malaria parasite, but it is convenient to break into the circle at the *sporozoite* phase, the form in which the parasites are concentrated mainly in the salivary gland of the mosquito. From here they pass to man when the insect bites. Then for a few days they disappear. Subsequent events prove that they are still alive and undergoing modifications, probably in the tissues of the body, but just what happens no one really knows, and to cover this ignorance it has been suggested that the parasites should be referred to at this stage as *cryptozoites*. The first time the parasites become visible in the human body is when they appear in the ring form either in, or attached to the surface of, the red blood-cells. After further development and upon the division of the nuclear chromatin material, the so-called *schizont* stage is reached, which then breaks up into numerous small bodies called *merozoites*. At the same time the host red blood-cell bursts, liberating these new forms into the blood-stream, where they seek other red cells and begin their multiplication yet again. The onset of fever coincides with this periodic rupture of the red cells, and the time-interval between rigors is a characteristic of the species of parasite causing the particular attack of the disease. After a few such cycles (*schizogony*), some of the parasites deviate from this course and differentiate while still in the red cells into male and female parasites known as *gametocytes*. These in time become free by destroying their host cells. They do not, however, divide again in man, but in course of time may be taken up by a mosquito partaking of a 'blood meal' from the human carrier. There is no need to detail subsequent events. Suffice to say that after further changes, in which sexual union is involved, the life history of the parasite turns full circle with the appearance once again of the sporozoites in the salivary glands of the insect.

When the investigations here described began, only three drugs were of importance in controlling human malaria. They were the naturally occurring quinine (and its near relations), and the synthetic substances mepacrine and pamaquin. Not one of these could be considered the perfect antimalarial. All produced toxic symptoms, and mepacrine in particular was a coloured substance which imparted a yellow stain to the skin. Quinine and mepacrine were restricted in their activity to the blood-forms of the parasite. In other words, they

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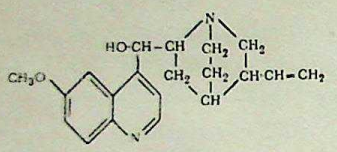
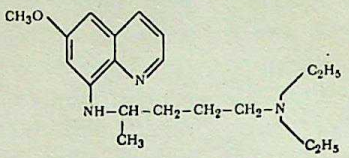
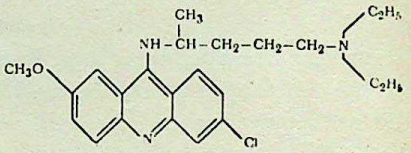
did not function until some time after the disease had entered the body, and then failed to produce radical cures. Pamaquin had a marked action against the gametocytes, preventing reinfection of the mosquito, and was also said by some workers to reduce relapse rates, but was so dangerously toxic that it could be used only under strict medical supervision. Finally, all these drugs were difficult to produce, and for this reason their use could not be extensive, for example, amongst native populations.



Quinine



Pamaquin



Mepacrine

The objective for further research was clearly then to produce a colourless, non-toxic drug, preferably of simple structure, which would be effective not only against the blood-forms, but against the earlier phases of the parasite, so that by acting as a true causal prophylactic it would eliminate the disease at the earliest possible stage.

Chemotherapy demands that, where possible, disease shall be studied first in small experimental animals, the smaller the better. There are several reasons for this. Firstly, direct experimentation with new drugs in human beings is undesirable, unless there is no alternative. Secondly, it is customary to administer drugs in dosages of so many grams per kilogram of body weight, and since many substances are extremely complex and their preparation even in the smallest amounts (1 gm. or less) is often a tedious business, the choice of small animals for experimental purposes allows the study of the action of the drug in the maximum number of 'cases.' Fortunately, many of the diseases to which man is subject, particularly some of the bacterial infections, can be reproduced in animals such as the mouse; and there exists a good chance that drugs discovered to be effective in this animal may subsequently prove active in the corresponding condition in man.

Malaria is less amenable to this kind of procedure. No small laboratory mammal is known which will 'take' human malarias. Forms of malaria are met with in the monkey tribe, but these animals cannot be considered small in the present sense, and in any event are probably the least tractable of experimental species. Some birds, however, can be infected by parasites related to those of human malaria. The parasite is transmissible through a mosquito, but is of a species different from that involved in human malaria. The parasite 'goes to earth' for a period of time after injection into the host, and then finally appears in the red cells of the blood. Suitable bird hosts are the young chick, duckling, Java sparrow, and canary. Each has its own peculiar susceptibilities to the several virulent parasite strains, called by names such as *Plasmodium* (or *P.*) *gallinaceum*, *P. lophurae* and *P. relictum*. A great deal of thought has to be given to the choice of the most suitable bird host and the most suitable parasite for laboratory investigations, bearing in mind that a wrong selection might mean the neglect of a drug valuable in human malaria, just because it was inactive, or almost inactive, in the particular experimental infection used. The counsel of perfection would be to run as many different strains in as many different hosts as is possible, thus minimizing the chances of such a happening, but in wartime Britain, when this decision had to be made, such a course was impracticable.

Space does not permit an account of the arguments adduced in support of the ultimate choice (a detailed account appeared in the December 1945 issue of the *Annals of Tropical Medicine and Parasitology*), but subsequent events have shown how wise was the selection of the young chick infected with *P. gallinaceum* in the initial tests for sorting out the compounds made by the chemists. Other hosts, infected with other strains of parasites, were not discarded, but used as 'second strings' to distinguish between drugs thought to act in different ways. An intensive study was made of that part of the life-cycle of the parasite which takes place in the chick, and it was tentatively suggested that in this species the sporozoite phase gives way to a *primary tissue phase* (or *exo-erythrocytic phase*), and this to the blood-forms. These in turn

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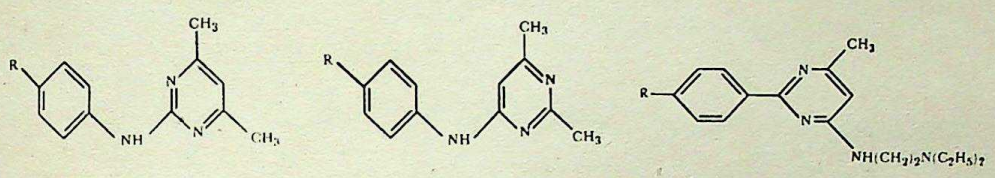
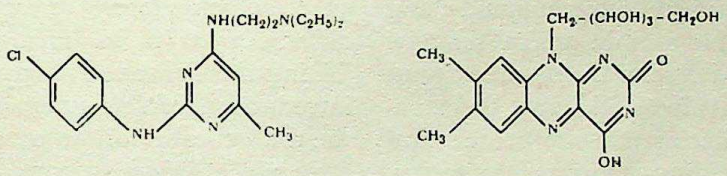
revert to a tissue phase which may be closely related to the primary tissue forms. This secondary phase might itself lead to more blood or *erythrocytic* forms, and so the cycle in the host would be maintained. It was obvious that wide differences might be expected between the detailed life histories of the parasite in the chick and of the different species of parasite in man, but, taking into account all the available evidence, it was considered that the existence and persistence of a secondary tissue phase in man, such as was over the world on the basis of the three drugs mentioned above were not likely to provide a solution. For a number of reasons the choice fell upon the pyrimidine nucleus. Firstly, the chemistry of this ring system had become familiar in the course of work on sulphapyrimidine derivatives, and it had moreover just been learned that these latter compounds were effective to some extent in controlling malaria. Secondly, it was a structure that lent itself to the easy introduction of those chemical groupings tentatively considered to be of anti-



(I) (II) (III)

R=H, OCH_3, Cl



(2666) (IV)

postulated for the chick, might account for the relapses which are met with in human malaria. With the chick test it was hoped, then, that it might be possible to distinguish between drugs which would act as true causal prophylactics, or as suppressants, or which would control the relapse rate.

When a new series of drugs is being investigated, it frequently happens that the first preparations exhibit but the merest trace of activity. Unless the biological test is highly sensitive, this trace-effect could easily be missed, and a chemical type that might ultimately have given drugs of great value would be passed by. One particular feature of the test developed in the present research was extreme sensitivity; and in addition it provided results, statistically sound, that distinguished between drugs of nearly equal activity. This told the chemists whether their chemical variations in a drug molecule were taking them nearer to, or farther away from, their goal.

The chemical aspect of the research has now to be considered. The initial step was to select a fresh molecular type for study. This was done deliberately, since it had become apparent that the extensive researches previously carried out all malarial significance; and thirdly, it was one of the 'vital' molecules occurring in many systems of physiological importance, such as the nucleic acids and numerous enzymes.

As to suitable ways of elaborating the pyrimidine ring to produce antimalarial drugs, consideration of the quinine and pamaquin molecules showed that these structures could be regarded as benzene derivatives containing methoxyl and associated with a ring nitrogen atom and a 'basic side chain.' The presence of chlorine in mepacrine suggested that this substituent might also promote antimalarial activity. The first preparations were very simple structures such as (I) and (II). These proved inactive. Dialkylaminoalkylamino side chains were then introduced into the molecules and (III) and 2666 were prepared. Of these, 2666 showed moderate activity as a suppressant against the blood-forms of the parasite in the chick. A preliminary clinical trial proved unsuccessful, but the first and greatest obstacle, that of discovering a lead, had been surmounted, and from then on the search for more active structures was intensified. The chemist always prefers to pursue his researches according to some plan, rather than to indulge in purely empirical variation of the

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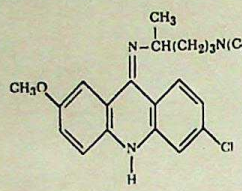
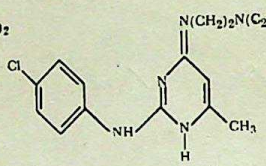
prototype molecule; and one of the most satisfactory methods in chemotherapy is to devise a hypothesis relating structure to biological effect, and then by suitable synthesis to seek to prove or disprove it. In the present instance several schemes were considered. One of these sought to explain the activity of 2666 on the basis of an apparent structural relationship to the growth factor riboflavine. This was in accord with a new view in chemotherapy, first postulated by D. D. Woods in 1940 to explain the activity of sulphanilamide, and soon afterwards stated in a more general sense by P. Fildes, which regarded some therapeutic agents as acting on organismal disease incitants, for example bacteria, by inhibiting the use of chemical factors essential for their growth or multiplication. This view nearly always seemed to imply a structural similarity between growth factor and inhibitor. Comparison of 2666 with the formula of riboflavine (IV) did indicate a slight formal resemblance between the two, and subsequently a biochemical investigation proved that, at any rate with respect to the growth of the organism *Lactobacillus casei*, these two compounds were antagonistic to one another. This was sufficient to warrant a research designed to enhance the antagonism, but, despite the preparation of a great many compounds, no material advance was made along these lines in improving the antimalarial action of 2666.

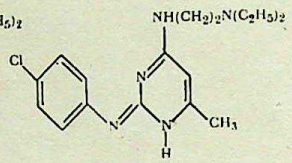
A second hypothesis was concerned with the tautomeric possibilities shown by the active structures, and, as events turned out, it was the development of this hypothesis which ultimately led to Paludrine. Schönhofer (the discoverer of pamaquin) had pointed out that the central nucleus of mepacrine was capable of undergoing tautomeric change through migration of the hydrogen atom of the 5-imino group to the ring nitrogen atom, giving the *p*-quinonoid arrangement of bonds seen in (V). A similar arrangement was possible in the 2666 molecule (VI), and indeed closer examination of the molecule showed that no fewer than six tautomeric structures could be formulated. Some of them, for example (VII), were *o*-quinonoid in type. Several months after 2666 came



(V)

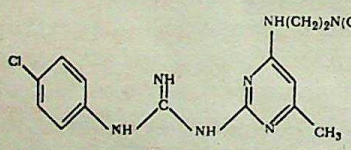


(VI)



(VII)

3349, which closely resembled the former but differed from it in having a guanidine group joining the benzene and pyrimidine nuclei. The introduction of this group still further increased the total number of tautomeric possibilities in the molecule. This was paralleled by an enhancement of antimalarial activity in the chick, and the discovery, for the first time in the new series, of an antimalarial action in man. Then another important observation was made. The two isomers of 2666, (VIII) and (IX), in which the groups attached to the pyrimidine ring were transposed, were found to be active and inactive respectively. When the tautomerism of these structures was analysed, it was seen that fewer possibilities existed for (IX) than for 2666, 3349, or (VIII). Moreover, the tautomers differed qualitatively from those of the active structures. In the latter group it was possible with each substance to formulate the molecule in such a way that the benzene ring and the basic side chain were linked through a conjugated system made up of alternate carbon and nitrogen atoms. Structure (VII) shows this in the case of 2666, and (X) the similar arrangement for 3349. In no way was



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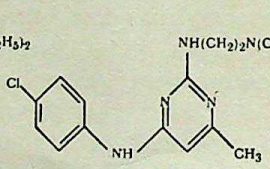
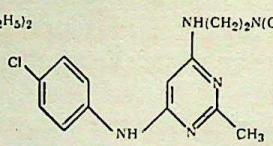


(VIII)



(IX)

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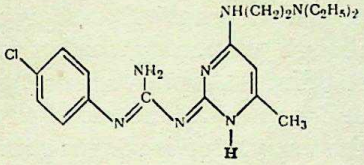
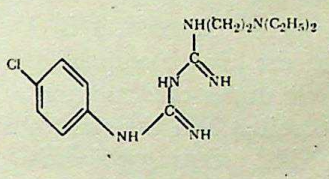
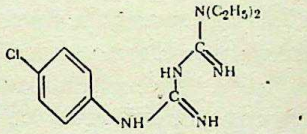
it possible to fit the inactive (IX) into the same picture. Here, it was suggested, was the secret of antimalarial activity in this particular type of chemical substance. That being so, it followed that a central ring was not an essential component, and that any related system providing the necessary alternation of nitrogen and carbon atoms with the appropriate double bonds might be antimalarial. The simplest molecular type conforming to these conditions was that of the biguanides, and compound (XI), formulated in an unconventional manner to show its relation to 2666, was



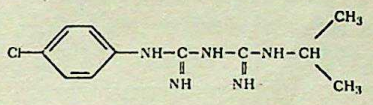
(X)



(XI)



(3936)



Paludrine (*base*)

prepared. This compound was inactive in the chick. It was, however, a much stronger base than 2666, and to make it more equivalent to the latter in this respect, part of the basic side chain was omitted and the new compound, 3936, synthesized. Activity then reappeared, and in a much wider sense, since for the first time an action against the exo-erythrocytic forms of the parasite in the chick was found. This held out the hope that substances of the biguanide class might function not only as suppressants but as causal prophylactics. The next step was to vary the 3936 molecule to see if a more effective compound would result. In November 1944, Paludrine was synthesized and proved the most active of the biguanide antimalarials. It is administered by mouth as the colourless hydrochloride, and in the chick and other experimental species it is many times as effective as mepacrine or quinine, with a much wider range of activity. Not only does it destroy the malaria parasites in the blood of the birds, but when administered at the correct time it even prevents the infection from developing. In man it is well tolerated; doses up to 1·5 gm. a day have been given, while as little as 10 mg. a day gives an action in the clinical phase of malaria. In addition it seems likely that the promise shown in the chick test will be paralleled in man, and that some measure of control of the disease will be possible from the time of infection by the mosquito. Preliminary results have indicated that it may be a true causal prophylactic in malignant tertian malaria, and a partial causal prophylactic in benign tertian malaria.

However, much still remains to be done before the final answer is known and the place of Paludrine in the armamentarium of tropical medicine defined; but at its lowest valuation it introduces a new chemical type into the chemotherapy of malaria, capable of considerable further exploration by biologist and chemist alike.

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Science in society: the fundamentals

E. F. CALDIN

Much recent writing on the social functions of science has been so coloured by political prejudice as to be of little value. In this very thoughtful article Mr Caldin has avoided this pitfall without evading the fundamental issues. He presses the claim, so well established but so often ignored, for the recognition of science as a source of truth as well as a means of improving the lot of mankind. Scientists should here find much food for reflection.

At this time, when a great expansion of scientific research in Britain is being planned, it is of unusual importance that the fundamental values of science should be well understood, so that the right men may be recruited and the right atmosphere maintained. The starting-point is the recognition that science has two aspects: (*a*) it is a source of knowledge, and (*b*) it can be applied to change material conditions. The present prestige of science is mainly due to its success in the latter role, but for its healthy development the former should be appreciated. A discussion of the significance of science as a source of truth is a pressing need.

This discussion is not made easier by the prevalence of a confusion between science and its application: between the understanding of nature and the manipulation of it for economic purposes. The confusion is not without excuse, because in the industrial organization of British economic life, and still more in the war-time mobilization of scientists, a large proportion of the men who leave universities with a training in science must bend their knowledge of nature to the control of matter to fulfil some technical requirement. But this is one of those occasions when a small mistake at the beginning is a grave error at the end; lack of clear distinctions at the start leads to a distorted conception of the place of science in society. Most of those who deal with this topic are really thinking of the place of technics in society, and of science only in relation to technics. It is necessary therefore to start by formulating some essential distinctions and elucidating their rational basis.

We may distinguish three main fields in which a man with a training in science may find himself working: (*i*) pure science, (*ii*) applied science, and (*iii*) technology. 'Pure science' denotes the study of nature for the sake of the good resulting simply from the understanding of nature, apart from any material benefits. Its method is to experiment (or observe) and then to interpret the results in terms of some hypothesis which, even though temporary, confers some degree of understanding. 'Applied science' uses the same method and arrives at the same sort of knowledge; but the knowledge is sought primarily for the sake of its applications. Between pure science and applied science there are many affinities. The material they work on is the same; the scientific methods used are the same; the theses produced are similar; there may be close contact between workers in the two fields. Moreover, men working on applied science may themselves be more interested in the knowledge gained than in its application, and may have as good an understanding of nature as their academic counterparts. No distinction can be drawn between pure and applied science in terms of differences in the training or competence of workers; or in organization; or in method, which in both studies is simply that of natural science; or even in the immediate outcome of the work, which for both is a new understanding of nature. None the less there is a difference, which is not at all subtle, between the general outlooks of men representative of pure science and of applied science; and the reason for it is to be found in the difference of the ends which are served by the two types of work. The end served by the study of pure science is the growth of mankind in the good attainable through merely understanding the world; that is, the advance in truth and goodness which is possible for men who study nature through science. The end served by applied science is the control of nature, its manipulation for the material welfare of men. The distinction of these ends corresponds to the distinction of the speculative and practical functions of the mind.

This difference of ends is not a sterile distinction. It corresponds to a very considerable difference in outlook on the part of the scientists

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concerned; to a difference of orientation in the choice of subjects for investigation, and in the emphases adopted in exposition; and ultimately to differences of opinion about the directions which 'fundamental research' should take—whether it should follow the inner logic of the knowledge gained, or should investigate systems of possible technical importance. The difference of ends also distinguishes technology from science. Technology is the application of the knowledge won by pure or applied science, in working out and practising techniques for the control of material nature; and whereas scientific research is concerned with winning and organizing knowledge, technological research is concerned with the application of that knowledge for extra-scientific purposes.

Some people—even some men of science—have had difficulty in finding the basis of the distinction between technology and the sciences. There are indeed considerable affinities between them. They both deal with the material world and with the same kind of knowledge about it; they both use experimental methods in research; they both employ men trained in science; they use similar vocabularies. Technology depends upon science for the knowledge which it applies, and sometimes provides the raw material of scientific advance, namely new observations or other stimulants to investigation. No distinction can indeed be made in terms of subject-matter, training of personnel, or terminology; nor, as things are, could the actual study of science easily be separated from technology, on which it has come to depend rather intimately for materials and apparatus. Yet it is impossible to maintain that science and technology are one and undivided without depriving distinctions of their meaning. The first distinction is again that of ends; the whole of the preceding discussion on applied science holds good for technology also, and the resulting differences of personal outlook and of the organization of work are even more marked. For instance, a technologist's problem is assigned to him and he is expected to provide a solution; whereas in science it is essential that there should be some freedom of investigation. A second distinction concerns method. The method of modern technological research consists in applying the results of science as far as possible and, where they are insufficient, conducting *ad hoc* experiments. If the system concerned is simple enough, and if the relevant scientific work has progressed far enough, it is only necessary to verify a result predicted on scientific grounds. But it often happens that too many unknown factors are involved, or that scientific data are not available over a sufficient range, or that several phenomena are concerned simultaneously; for these or other reasons it may be necessary to try various expedients until one is successful.

In such experimental investigations there are several important analogies with the experiments of science: variable factors are controlled, and the correlation of variables is employed. But the method as a whole differs radically from that of science. The experimental part of science, being directed towards understanding the system under investigation, is essentially connected with the other part of scientific method, namely, the formulation of explanatory hypotheses; an experiment which leads to no new understanding is a failure, and experiments are commonly designed in the light of some hypothesis in order to verify it or disprove it. The experimental part of technology, on the other hand, except in so far as it makes use of knowledge already won by science, uses simply the method of trial and error; it does not as such lead to any new understanding of nature. Technology is usually content to tabulate observations in a form convenient for achieving certain specific practical aims; it does not seek to understand the relations between the observations. Technology presupposes scientific understanding, but does not normally contribute to it. Tables of quantitative data, however extensive and accurate, do not constitute scientific knowledge, though they may be raw material for the scientist. A third distinction is the restriction in technology of the field of interest; many phenomena of great scientific interest are useless to technology and are ignored by it—eclipses, for example, and earthquakes.

With these differences of aim, method, and field of interest in mind, it does not seem possible to maintain (as some would like to maintain) that science and technology are indistinguishable as well as indivisible. Much of the current writing on the place of science in the post-war world is really about technology, with science considered only as part of the necessary basis for it. That technology will be of major importance to Britain, no one will deny; but the question of the place of technics in society raises wholly different problems from that of the place of science in society. Moreover, scientists have special qualifications to deal with the second question, but with regard to the first they can speak only as citizens. It is with the second that the rest of this study is concerned.

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The important problems for scientists and others with some education in science concern its influence on their thought and practical life, and hence on their fellow-men. For life is a unity; the scientific part of life affects the rest; a scientist becomes, in and through his scientific work, a better man or a worse; and his influence on his fellow-men is correspondingly helpful or harmful. It is therefore important to understand how science ought to be integrated with the rest of a scientist's life, and how this bears on his social influence.

The key to this integration is that scientific life is a version of rational life, an adaptation to a particular activity of the principles common to all rational life; consequently, if rightly lived, it should develop those qualities which make rational living possible in other departments of life. Scientific life is a type of life lived according to right reason. First, it demands the experience of the senses; not haphazard experience and hearsay evidence, but careful observation and intelligent searching; a mind alert for novelty but trained also in cautious verification. Second, it demands that observation shall be interpreted by reason, which brings order into the data of sense; it requires rigorous logic, controlled imagination, intellectual insight, clear analysis, and wide synthesis. It requires that we learn about nature from experience (as distinct from spinning myths) and that we interpret that experience by reason (as distinct from merely remembering or applying it). Third, it is characterized by a continual interplay of experiment and theory; experiments suggest hypotheses, hypotheses in turn suggest experiments which may verify them. Scientific life, then, requires a rational unity of thought and action. Fourth, it is a developing tradition: neither a code of unalterable rules, nor, on the other hand, a formless collection of varying authenticity, devoid of established criteria for judging new developments. That is, the scientific spirit will tolerate neither a sterile immobility nor a rootless fickleness; scientific beliefs need periodic overhaul and constant adjustment. Fifth, as a consequence, scientific life requires freedom: freedom of thought, of discussion, of publication, and of investigation. Sixth, scientific work is a social as well as a personal enterprise. All scientists must take on trust a vast body of facts established by their colleagues and predecessors, and it seldom happens that any important field of scientific investigation is monopolized for long by one man. Consequently, the practice of science requires both personal integrity and respect for one's colleagues; tolerance for others' opinions, and determination to improve one's own; and care not to overstate one's case or to underrate that of others. Thus a mental 'climate' is favoured which is a balance of appreciation and criticism.

All the six general principles named belong also to other studies and indeed to any rationally conducted enterprise, from philosophical research to farming. Every student can recognize in them the principles of his own speciality. But in pursuing natural science we use a special adaptation of those principles, a particular version of rational method. Historians use another version, philosophers yet another; craftsmen, business men, housewives, all have their own special rational habits adapted to the work in hand. The method of natural science is not the sole and universal rational way of reaching truth; it is one version of rational method, adapted to a particular set of truths. The point needs emphasizing, both to point out a common mistake and to show how to correct it. Large numbers of people have been misled into thinking that the procedure of natural science is the royal road to truth in every field; that what cannot be proved by science cannot be true; and that metaphysical propositions, for example, are meaningless or at any rate unprovable. The mistake here lies in confusing the part with the whole—scientific method with rational method. But we can substitute an important truth for the mistake if, agreeing that science is not to be divorced from other rational pursuits, we find their connection in this: that science is not only a version but a microcosm of rational life. By this is meant that in studying science and becoming familiar with that form of rational activity, one is led to understand rational life in general: one grasps the principles of all rational procedure through practice of one form of it. It should then be easier to adapt those principles to other studies and to life in general. Scientific work, in short, should be a school of rational life.

In parenthesis, it may be remarked that one of the greatest needs of contemporary scientific and intellectual life is a clearer understanding of the relations and differences between the methods of natural science, philosophy, history, literature, and so on. It is time to develop the comparative study of rational methods, a field in which work has been piecemeal and scattered. We need a survey which will show exactly how the diverse methods of the various rational disciplines are all

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versions of the general method of reason working on experience, and yet are all legitimately different. A constructive account such as this could do much to reduce the intellectual malaise of our time, which cries out for a synthesis. Lacking one, there is a tendency to erect general systems on partial aspects of the whole—treating, for example, the economic element in social history as a sufficient basis for the interpretation of history; or, at best, resting content with very inadequate accounts of the relations between rational disciplines—distinguishing science and philosophy, for example, in terms of some facile distinction of objective and subjective or realist and idealist. Endless confusion would be saved if it were more widely realized that natural science is restricted, by its very method, to the study of a limited field from a particular angle, and has nothing to say (for example) about the principles of ethics, or the freedom of the will; these are dealt with by philosophy, with its wider field, more generalized approach, and correspondingly different methods. Scientific life can be a microcosm of rational life, but it cannot claim to be the macrocosm.

These views may be applied to the question of the 'social function of science.' There are in fact two quite distinct (though not separable) ways in which scientists as such discharge their responsibilities to their fellow-men. One is through the application of science to make easier the material conditions of life. But the ease and frequency with which science is misapplied make this quite inadequate as a justification for the existence of science. A much stronger case can be made for science as a social force in terms of its approach to truth than in terms of its usefulness. Those whose work is primarily concerned with science itself, whether in teaching or research, can fulfil a highly important social function simply by their living devotion to the conservation, advance, and propagation of scientific life. For if science can be made a real school of rational life, in virtue of its being a type and microcosm of rational procedure, it must necessarily contribute to the personal development of those who follow it.

Anyone who has seen the general intellectual development which can result from the proper teaching of science at a university must admit that the academic scientist can contribute not a little to the personal growth of young people. Society at large benefits from such personal development; for its vitality depends upon the vitality of individual people and their intellectual and moral ideals. Again, it will probably be agreed that the fundamental values of reason, and in particular the value of truth and the dignity of the human person, stand in great need of buttressing. It may be that natural science will be one of their supports, for science has an advantage over history, or philosophy, or literature, as a representative of reason, in that so long as it remains alive at all, it cannot be wholly false to the true rational spirit. False science is easily disproved, by experiments reproducible at will; moreover, it would fail if attempts were made to apply it. No one can coerce nature; it cannot be persuaded by the will or affected by the imagination, whereas most other studies are liable to perversions which are much more difficult to eliminate and may greatly weaken the work of whole schools of thought and generations of scholars. At all events, while the prestige of science stands so high in the common estimation, scientists have a special responsibility to uphold reason in science and in general.

The application of this line of thought to the question of the 'planning of science' may be briefly suggested. Planning in science and planning the application of science are two different things. Research in technology, and to some extent in applied science also, is fittingly directed towards solving problems indicated by some outside authority—the problems of health or of national defence, for example. But since the end of pure science is knowledge, rather than use, it must follow its own inner dialectic and cannot be directed by any authority external to itself; moreover, as is often pointed out, any attempt at external direction is fatal to the quality of the work produced. The part of external authorities is to provide facilities rather than to apply compulsion. The same applies to the planning of science from within: projects for allotting work and preventing overlapping by compulsion are not in the true spirit of science.

In this short exposition of the primary function of science, the attempt has been made to retain what was positive in the older apologia of science, which represented its value as due to its loyalty to truth, and to complete it by re-stating it in terms of personal life and the good of persons. At the same time the view outlined cannot be accused of favouring a selfish or irresponsible attitude. No apology is made for dwelling upon fundamental truths which may seem trite to many; for these truths should be the presuppositions of practical decisions, and if they are replaced by false presuppositions the consequences may be grave indeed.

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Cosmic rays and their origin

A. C. B. LOVELL

It is now generally accepted that the cosmic radiation at sea level consists mainly of two components—the soft component composed of electrons, positrons, and photons, and the hard penetrating component chiefly composed of mesons. Is is also generally believed that these two components arise mainly as a result of secondary processes in the earth's atmosphere. This article gives a brief description of recent work and of previous experiments.

THE ELECTRON COMPONENT OF COSMIC RAYS

The intensity of the cosmic ray electrons at sea level is about 0·3 electrons per sq. cm. per minute, very nearly equally divided between positive and negative electrons. This represents about one-third of the total number of ionizing cosmic ray particles found at sea level. The distribution of energy in these electrons has been measured up to about 2×10^{10} electron-volts (eV) and varies inversely as the square of the energy (E). It is believed that this inverse square law extends to considerably higher energies. The upper limit of the energy range is not yet known but it is certainly more than 10^{15} eV and may be over 10^{20} eV.

THE CASCADE PROCESS OF MULTIPLICATION

The application by Bethe and Heitler [1] of quantum mechanics to describe the behaviour of an electron in its passage through matter indicated that when an electron of high energy passes through matter it loses energy in two ways:

(*a*) By collision with extranuclear electrons of the atoms through which it passes. If sufficient energy is communicated in the collision the electron may be removed and the atom ionized, otherwise the atom may be raised to an excited state and emit a photon.

(*b*) If the electron passes close to the nucleus of the atom it comes under the influence of strong electric fields and is subject to large accelerations. It then loses energy by radiation (production of photons).

The subsequent application of this Bethe-Heitler theory to the study of cosmic rays by Bhabha and Heitler [2] and also by Carlson and Oppenheimer [3], in 1937, gave a satisfactory explanation of one of the most frequently observed phenomena in cosmic rays, namely the occurrence of showers, or simultaneous groups of electrons. This method of shower production is known as the *cascade process* and is illustrated diagrammatically in figure 1.

The incident electron passes close to the nucleus of an atom at α and a photon is radiated, which subsequently passes close to the nucleus of another atom at β, and produces a pair of positive and negative electrons. Meanwhile the original electron produces another photon at γ, which in turn produces an electron pair at δ. So the process continues and the system loses energy at an increasing rate. If, in its path, the shower encounters a sufficiently large number of atoms, the process of subdivision reaches a maximum, after which the energy of the electrons is so low that they become absorbed without production of further particles. The thickness of material necessary to give this maximum number of particles is predicted by the cascade theory. It increases as the energy of the original electron increases.

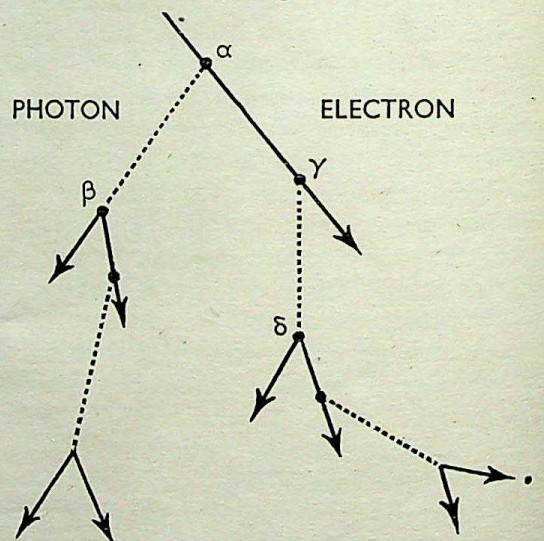

FIGURE 1 – *Diagrammatic illustration of the cascade process of shower production.*

Figure 3 shows a cloud-chamber photograph

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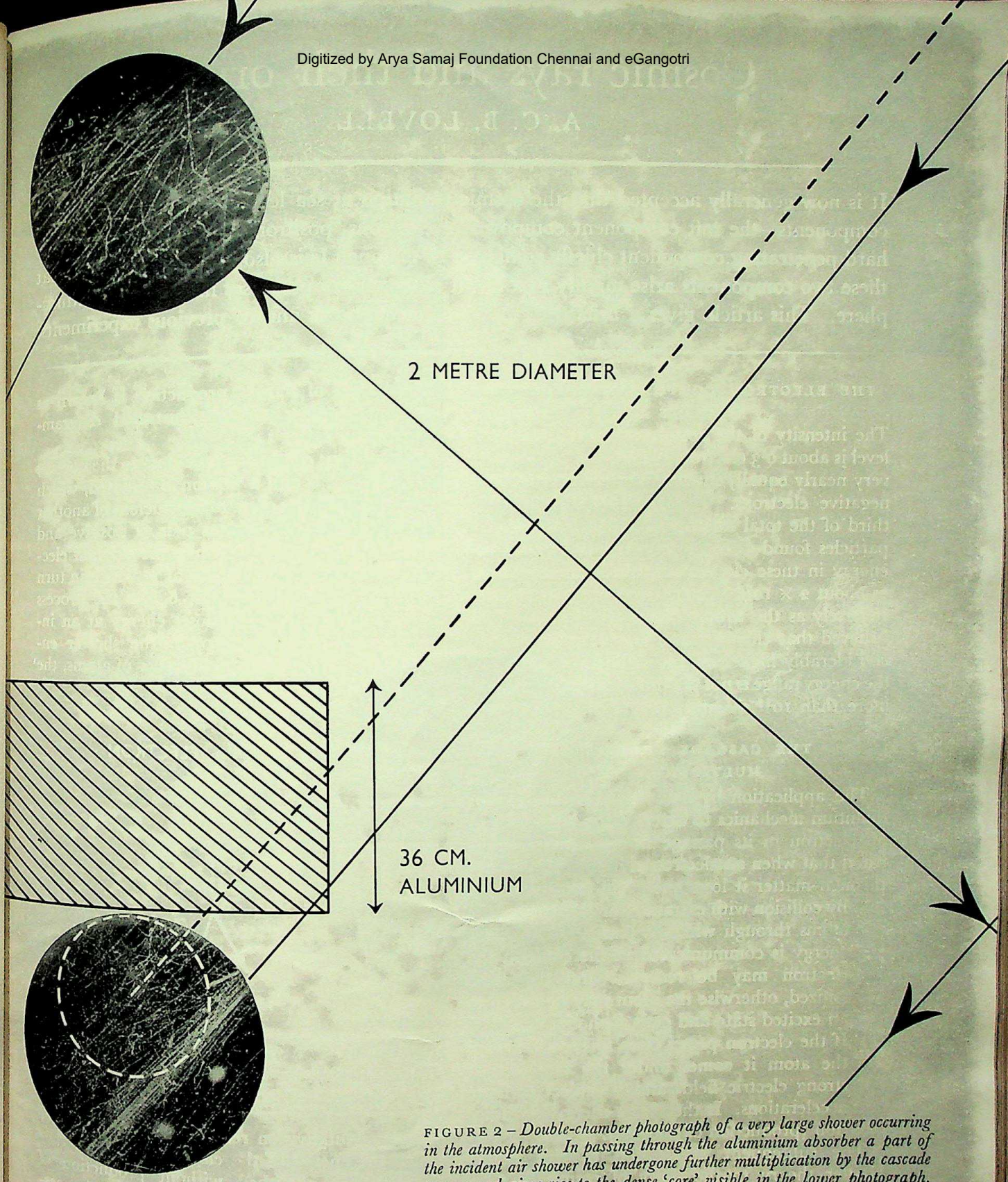

FIGURE 2 – *Double-chamber photograph of a very large shower occurring in the atmosphere. In passing through the aluminium absorber a part of the incident air shower has undergone further multiplication by the cascade process and gives rise to the dense 'core' visible in the lower photograph. These photographs were obtained with the apparatus shown in figure* 5 *and the reproduction is to scale except in the case of the two actual photographs which are* × 2 *scale. The centre line indicates the estimated direction of the particles in the air shower which gave rise to the dense core. The asymmetry in the scale has made this line pass much closer to the edge of the aluminium than it should do. (The actual position of the lower chamber and the location of this line through the aluminium are shown in dotted line.) It was estimated that the main part of the shower occurred in a cylinder of about* 2 *metres diameter as indicated by the outer lines and probably contained some* 50,000 *particles of exceedingly high energy.* (*Photograph by Dr J. G. Wilson and the Author.*)

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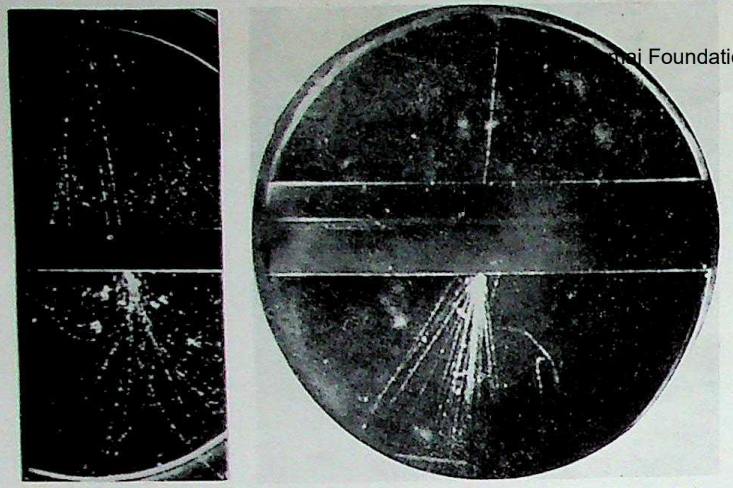


FIGURE 3 (*left*) – *A typical cascade shower of electrons and positrons. The cloud chamber was in a magnetic field of* 10,000 *gauss and the momentum of the particles was measured from the curvature of their tracks.*
(*Photograph by Dr J. G. Wilson.*)

FIGURE 4 (*top centre*) – *Cloud-chamber photograph of a 'knock-on' shower. The particle in the top half has already traversed* 20 *cm. of lead and is a meson. It produces a shower of electrons and positrons in the lead plate across the centre of the chamber. (The lead plate was* 1·8 *cm. thick but a metal box containing a Geiger counter rested on top of it.)*
(*Photograph by the Author.*)

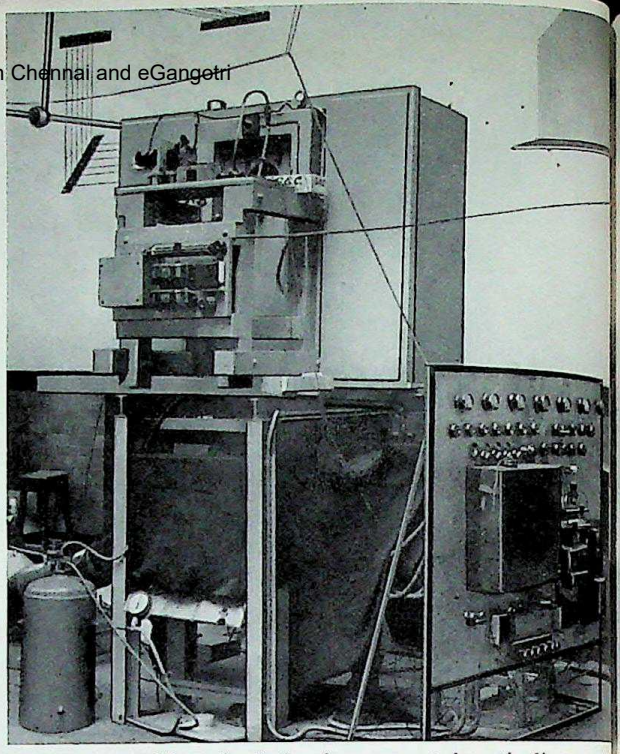
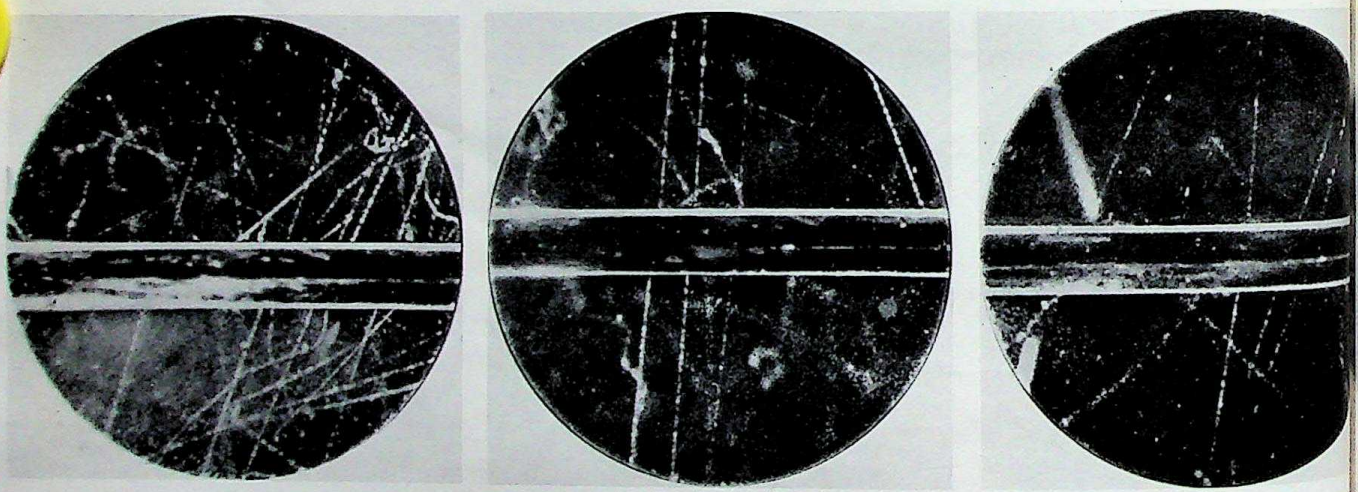


FIGURE 5 – *Two cloud chambers, mounted vertically one above the other, separated by* 36 *cm. of aluminium, which photographed the big cosmic ray shower shown in figure* 2. *The lower chamber was used in a magnetic field of* 1,000 *gauss. A part of the cooling fan is seen on the extreme left of the photograph.*



FIGURES 6, 7, 8 – *Examples of cloud-chamber photographs obtained with the apparatus illustrated in figure* 10. *These particles must have penetrated* 53 *cm. of lead in order to have operated the chamber. Moreover they pass through a* 2 *cm. lead plate in the chamber without multiplying, which proves them to be mesons.*
(*Photographs by Dr J. G. Wilson.*)

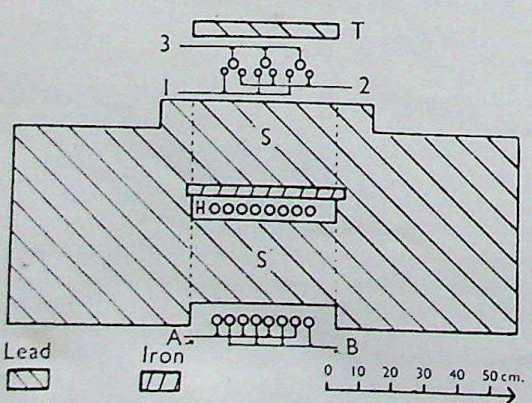


FIGURE 9 – *The counter apparatus used by Jánossy and Ingleby to prove the existence of showers of mesons. The weight of lead used in the experiment was* 15 *tons.*

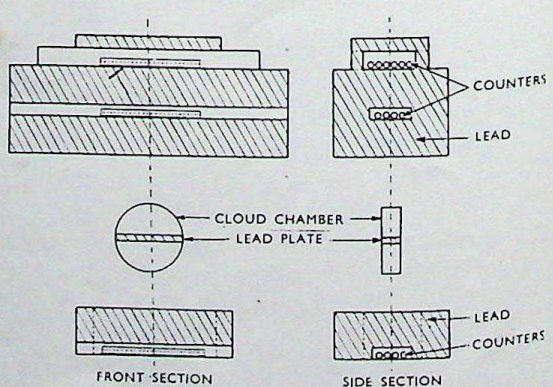


FIGURE 10–*Arrangement of counter-controlled cloud chamber used by Rochester to photograph showers of mesons. The total vertical thickness of lead was* 53 *cm.*

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of a characteristic electron cascade shower of this type. The particles in the top half of the photograph are positive and negative electrons with energies of from 5×10^7 eV to 4×10^8 eV. These are part of a cascade shower starting outside the cloud chamber, probably in the atmosphere. On passing through a 2 cm. gold plate across the centre of the chamber they multiply still further by the cascade process.

Although the quanta and secondary electrons produced by such processes will be projected in the general direction of the incident electron, it is obvious that if the original electron has a very high energy a large number of secondary particles will be produced in the shower, which may eventually spread out to cover a considerable area. The existence of exceedingly large showers in the atmosphere was first shown by Auger and his collaborators in 1939 [4]. They found coincidences in Geiger counters which were separated by distances up to 300 metres. In the same year, Lovell and Wilson [5] obtained cloud-chamber photographs of a portion of these big showers originating in the atmosphere by using two cloud chambers separated by distances of up to 20 metres, and also with one chamber mounted vertically above another.

These chambers were counter-controlled in such a way that photographs were taken only when a large number of electrons passed through both chambers simultaneously. Figure 2 is a scale photograph of one of the big showers obtained. This shower contained at least 50,000 particles; such extensive showers occur very infrequently.

Figure 5 shows a photograph of the double chamber apparatus with which this shower was observed. Such big showers occur very infrequently.

THE ORIGIN OF THE COSMIC RAY ELECTRONS

The cascade theory does not touch the question of the origin of the incident electron responsible for initiating the shower. With the possible exception of some of the very extensive air showers, the electrons found at sea level cannot be the direct result of primary electrons incident from space on the earth's atmosphere, since (except for those with very high energies) the range of the primaries would not be great enough. It is now known, however, that two other processes capable of producing electrons or electron showers can account satisfactorily for the electron component of cosmic rays found at sea level. These are (i) the decay of the meson into an electron, and (ii) the production of cascade electron showers by the *knock-on process* from mesons.

Meson Decay. In 1937, Anderson and Neddermeyer [6] obtained evidence that particles of mass intermediate between the mass of the electron and proton were present in cosmic rays, and it soon became evident that these particles were in fact mainly responsible for the so-called hard or penetrating component of cosmic rays. The mass of these 'mesons' is now believed to be about 180 times the electron mass, and they possess the same charge as the electron (positive or negative). Such a particle was postulated by Yukawa [7] in 1935 in order to explain the forces inside the atomic nucleus. Yukawa's theory also postulated that this particle should 'decay' spontaneously into an electron and a neutrino, and that it would have an average lifetime of about 10^{-7} second.

Experimental evidence that the cosmic ray mesons did in fact decay was soon obtained. For example, it was found that the absorption of the mesons differed for equivalent masses of heavy materials and air, and this can be explained only if in addition to an absorption dependent on mass, there is an independent spontaneous loss of particles increasing with the path traversed. The average lifetime for a meson at rest is found experimentally to be 2×10^{-6} second, in reasonable agreement with Yukawa's prediction. More direct evidence of the decay of the meson was secured in 1940 by Williams and Roberts [8], who obtained a cloud-chamber photograph of a meson stopping in the gas of the cloud chamber and an electron emerging from the end of the meson track. The decay of the meson is, therefore, one process which gives rise to cosmic ray electrons. Moreover, if the meson decays when it possesses considerable kinetic energy, the decay electron will also be of high energy and hence will give rise to cascade showers of electrons as described above.

Knock-on Showers. The two main processes by which an electron loses energy when it passes through matter have already been discussed. In the case of mesons, quantum theory predicts that the main process of energy-loss is by collision with extranuclear electrons which are 'knocked-on' and are then able to produce a cascade shower of electrons.

This knock-on process is responsible for the electron component found under large thicknesses of lead and deep underground. The process can be demonstrated in cloud-chamber experiments by

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working under say 20 cm. of lead. The probability that a high energy electron may traverse such a thickness and emerges as a single particle without producing a shower is negligible. Hence most single particles appearing beneath the lead will be mesons. If these are now photographed in a cloud chamber with a lead plate across its centre, they occasionally produce showers in the plate. For example, figure 4 shows a single particle in the top half of a cloud chamber which has already penetrated 20 cm. of lead and is therefore a meson. In passing through the lead plate in the chamber it knocks-on an electron which then produces an ordinary cascade shower. The number and size of such showers found with such an arrangement agree well with theoretical calculations based on the above mechanism.

THE ORIGIN OF THE MESONS

It is now believed that the processes of meson decay and knock-on of electrons by mesons can provide an explanation of the number of cosmic ray electrons found at sea level. The fact that the mesons decay spontaneously with an average lifetime of about 10^{-6} seconds means that they must be created near the earth. Assuming that they are created in the earth's atmosphere, the most vital questions are: what are the primary particles? and how are the mesons created, singly, in pairs (positive and negative), or as showers of many simultaneous mesons? The greatest uncertainty prevailed on these points up to the outbreak of war. Some workers claimed to have proved the existence of showers of mesons, and in 1939 Braddick and Hensby [9] obtained a convincing cloud-chamber photograph of a pair of mesons. The work carried out in Manchester during the war by Jánossy, Rochester, and their co-workers probably settled the question.

Counter Experiments. The first proof of the existence of showers of penetrating particles was obtained by Jánossy and Ingleby [10] using a counter apparatus illustrated diagrammatically in figure 9. A similar experiment was carried out independently by Wataghin and his co-workers [11] in Brazil.

This apparatus worked by recording *five-fold coincidences* 1–2–3–A–B, and evidence as to the numbers of particles involved in such a coincidence was given by the eight counters H which controlled small neon indicators. The results could be interpreted only on the assumption that the showers causing the coincidences were composed of associated penetrating particles. Moreover the results with and without the absorber T showed that less than half of the penetrating showers come from the atmosphere, whilst the rest are produced in the absorber.

Further experiments of this type by Jánossy and Rochester [12] during the period 1940 to 1943 gave the following additional information:

(*a*) Some of the penetrating showers extend over a large area.

(*b*) About one-third of the penetrating showers are produced by a non-ionizing radiation more penetrating than photons (probably neutrons).

Cloud-chamber Experiments. In 1944 Rochester [13] obtained 30 photographs with a counter controlled chamber arranged as in figure 10.

The chamber was operated by a sevenfold coincidence, which meant that about 95 per cent. of the coincidences were caused by penetrating showers. Eighteen photographs showed particles passing through a 2·3 cm. lead plate inside the chamber without multiplication (proving them to be mesons) and nine of the eighteen photographs showed showers of two or more particles. Examples of these photographs are shown in figures 6, 7, and 8; they demonstrate beyond doubt the existence of associated penetrating particles.

The Theory of the Origin of Mesons. The theory of the origin of mesons suggested by Hamilton, Heitler, and Peng [14] appears to be the most likely explanation of the results of the above experiments. In this theory the incident particles are considered to be protons. A single meson is the result of an inelastic collision of such a proton with a proton or neutron, while a shower of mesons is the result of a collision of the incident proton with an atomic nucleus containing several protons. At the time of writing, Heitler and his co-workers at the Dublin Institute for Advanced Studies are still working on this problem, and it is not yet certain if protons incident at the top of the atmosphere can alone explain the ultimate production of the soft component at sea level, or whether it is necessary to invoke the presence of very high energy electrons in the incident beam to account for the extensive air showers found at sea level.

THE ORIGIN OF THE COSMIC RAY PARTICLES INCIDENT ON THE EARTH'S ATMOSPHERE

Recent experiments and theoretical developments give some evidence that the cosmic ray particles incident on the earth's atmosphere may be protons. There is, however, no scientific

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evidence as to how these particles originate or where they come from. There have, of course, been many speculations, such as that they originate in the building up or annihilation of matter in interstellar space, but the extent of our scientific knowledge is that the intensity with which they bombard the earth's atmosphere is about thirty particles/sq. cm./minute, and that the average energy of the particles is about 6×10^9 eV. The energy which these primary rays bring to the earth is therefore $1{\cdot}8 \times 10^{11}$ eV/sq. cm./min. Taking the radius of the earth as approximately 4,000 miles this represents a total energy flow of $1{\cdot}5 \times 10^{18}$ ergs/min. over the whole surface of the atmosphere. But one horse-power is equivalent to $7{\cdot}46 \times 10^9$ ergs/secs.; hence the total energy of the primary rays is approximately $3{\cdot}4 \times 10^6$ h.p. This is comparable with the developed water-power resources of the world (3×10^7 h.p.). It is, however, minute compared with solar energy (5×10^{22} h.p.) of which 10^{14} h.p. reaches the surface of the earth.

THE "THIRD" COMPONENT OF COSMIC RAYS

Although electrons and photons (soft component) and mesons (hard component) together account for nearly all the cosmic ray particles found at sea level and in the lower atmosphere, there is in fact an almost vanishingly small third component. This represents only about 1/10,000 of the total cosmic ray intensity at sea level. It certainly contains positive protons, and there is a growing belief that it may also contain negative protons although none has yet been observed. It also contains neutrons or some neutral particle more penetrating than photons, otherwise the results of Jánossy and Rochester on the production of penetrating showers in an absorber at sea level cannot be explained.

FUTURE RESEARCH

Cosmic-ray research is fast becoming a technically difficult and expensive process. Thus, in order to verify experimentally the outstanding uncertainties described in this article it will be necessary to carry out laboratory experiments in the upper atmosphere, both to discover the nature of the incoming particles and the processes by which mesons are produced. Such experiments will involve manned balloon ascents into the stratosphere and high altitude work in aircraft with specially designed, lightweight, high-altitude cloud chamber and counter equipment. It may also need experiments in rockets of the V_2 type. The extension of the measurement of the energy distribution in the rays at sea level to energies above 10^{10} eV will need the construction of a powerful magnet, and already in Manchester the construction of a magnetic spectrograph consisting of two 10,000-gauss magnets is being planned. Also in Manchester the possibility of detecting the big atmospheric air showers by using radar technique is being explored.

CONCLUSION

The particles incident from space on the earth's atmosphere are probably protons. In the upper layers of the atmosphere these produce positive and negative mesons singly and in showers by collisions with protons, neutrons, and atomic nuclei. The mesons produce electrons and photons (*a*) by decay into an electron and neutrino, (*b*) by 'knocking-on' an electron in a direct collision (the electron in both cases subsequently producing a shower by the cascade process). The intensity of the resultant cosmic ray beam at sea level is about one particle/sq. cm./minute, of which about one-third are electrons. Some of the very big extensive air showers may not be produced by these processes but may require the presence of some very high energy electrons (10^{15} to 10^{20} eV) in the incident proton beam. Protons and possibly neutrons are also found at sea level but these comprise only 1/10,000 of the cosmic ray intensity.

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Book reviews

NATURE AND USES OF COLLOIDS

Colloids. Their Properties and Applications, *by A. G. Ward. Pp.* 133. *Blackie & Son Limited, London.* 1945. 5*s. net.*

This admirable little book gives an extremely clear and well balanced account, for the non-specialist scientific reader, of the properties of colloids, the methods used in their investigation, and some of their principal applications in industry; biological applications are also dealt with, though less fully. It includes a brief but clear account of modern views on the atomic structure of matter and on the forces of cohesion in matter. Among the industrial colloids treated are rubber, including synthetic rubbers, natural and synthetic fibres, clays, paints, adhesives, etc. There is no attempt to enter into much detail, but the clear manner in which the organic and physical chemistry of these substances is set out, and related to their valuable properties, would be very difficult to surpass in so small a compass. The book is not intended as a detailed textbook; but it might well be put into the hands of a student about to begin the study of colloids, to provide him with a general view of the whole field. It is up to date, and looks forward as well as surveying what has already been done.

N. K. ADAM

WAVE MECHANICS FOR BEGINNERS

Elementary Wave Mechanics, *by W. Heitler. Pp. viii* + 136. *University Press, Oxford.* 1945. 7*s.* 6*d. net.*

Professor Heitler—now at the Institute of Advanced Study in Dublin—is well known as a distinguished contributor to the quantum theory of radiation; together with London he made the first really significant step in understanding the quantum theory of the chemical bond. As we should expect from his earlier book on radiation, his new book on elementary wave mechanics, originally given as a course of lectures to physics and chemistry students at Dublin, is very readable; indeed it is possible to sit down and read it through at a single sitting without feeling unduly tired. The book is intended for people with no previous knowledge of the subject and with no particular mathematical attainments. The actual mathematics is reduced to a minimum, but by a wise choice of method it is surprising how well it explains, or at least makes plausible, much of the more involved parts of the subject. It is refreshing to find a book that justifies its title of *elementary* without being trivial.

A book of 136 pages cannot possibly include everything, even in elementary wave mechanics. But it is hard not to regret the absence of any account of scattering problems, structure of the nucleus, metallic cohesion, harmonic oscillators and rotators, and selection rules, the majority of which contrive somehow to find a place in most elementary text-books. However, within the restricted framework set by the author, an extremely clear account has been given of the derivation and meaning of the Schrödinger wave equation, and of its application in the structure of an atom and the formation of molecules. What has been done is, with few exceptions, well done. It is a pity there was not more of it.

C. A. COULSON

X-RAYS IN THE STUDY OF METALS

An Introduction to X-ray Metallography, *by A. Taylor. Pp.* 400. *Chapman & Hall Limited, London.* 1945. 36*s. net.*

X-rays have found such important applications in the study of metals that some knowledge of the subject has become indispensable to every research worker in metallurgy. Dr Taylor's book admirably fulfils its purpose of describing the methods of applying X-ray methods to the study of metallic structures and of indicating the principal results obtained. Information is given which will enable the worker to select the best type of tube and of target for a particular task. An account is given of the way in which the arrangements of the atoms in a solid affects the X-ray pattern, of the means of determining phase boundaries in thermal equilibrium diagrams and of textures in mechanically deformed structures, and of the measurement of grain size. A final description is given of the use of X-rays in the examination of castings and forgings, a use not dependent on crystal structure. This includes a section on micro-radiography, using thin sections of alloys, a method which, it is often forgotten, was employed by Heycock soon after the discovery of X-rays, but which now seems to have no advantage over microscopical methods. As the theory of the subject is adequately explained and the methods are fully illustrated, the book should be invaluable to metallographers. Although it is produced in conformity with standards of economy imposed during the war, both printing and production are of high quality.

C. H. DESCH

FERTILIZERS: FOR AND AGAINST

Chemicals, Humus, and the Soil, *by Donald P. Hopkins. Pp.* 278. *Faber & Faber Limited, London.* 1945. 12*s.* 6*d. net.*

This is an admirable book. It examines the accusations of the pro-humus anti-fertilizer school in the clear, simple, and objective manner of an experienced judge putting the issues before the jury. The book is, in fact, a summing-up, for it is divided into two parts: I, the case for fertilizers; II, the case against fertilizers. Part I proceeds on conventional lines, and the mass of reliable scientific evidence is presented in very fair and restrained terms. It is in the handling of Part II that the author specially distinguishes himself. It would have been so easy to take the romantic exaggerations of the 'muck and mystery' school as the main target. Instead, the author concentrates his analysis on the statements of the sober-minded pro-humus writers. He has a difficult task, for some of them are—perhaps unconsciously — consummate guerilla tacticians, dodging from earthworms to the Cheshire doctors' 'Medical Testament,' from 'poisoned' crops to mycorrhiza, as one position after another becomes untenable, and sending suicide squads against Experiment Stations and statistical plot-techniques. But in Part II the author rounds them up, and shows convincingly that pro-humus evidence—and there is plenty—is not necessarily anti-fertilizer evidence. The conclusion is that humus and fertilizers are both jointly needed. They are complementary, not antagonistic; and, in any case, a wholly organic-manure civilization has been, for many years now, a stark impossibility.

B. A. KEEN

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ENDEAVOUR

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Education for science

Of the many changes in science which have marked the past few decades, none is more arresting than the vast acceleration in the rate at which new facts relating to natural phenomena have been accumulated. These facts are, of course, the essential raw material of science, and their recent profusion is a healthy sign. At the same time, their intrinsic importance may easily be overestimated. The advancement of science depends not only on the discovery of new facts but upon their value for the establishment of new principles or the confirmation of accepted ones. A few simple experiments, for example, were sufficient to confirm Dalton's faith in his atomic theory, but only the genius of a Dalton could have perceived the full implication of the facts or have shown that a great body of existing knowledge could now be summarized in a single generalization. The indispensability of facts, which must always make their discovery one of the main tasks of scientific research, is matched by the indispensability of those abstract qualities of insight, reasoning, and critical judgment necessary to their full appreciation.

In laboratory facilities and in scientific training the scientist of today is far better equipped than his predecessors of even two or three generations ago. It is nevertheless questionable whether the modern scientist has in general gained that broader outlook for which the tremendously increased importance of science so clearly calls. No one would wish to deny that, in the British Empire and Commonwealth and throughout the rest of the civilized world, there are many scientists of outstanding merit, whose brilliance—both within science itself and in wider fields of human affairs—is as great as that of the leading figures of any age. Their number is, however, relatively small in proportion to the tens of thousands for whom science is little more than a means of making a livelihood, and who—if they reflect upon the matter at all—are at best inclined to regard the significance of science to mankind as wholly utilitarian. Such a state of affairs perhaps becomes inevitable in any professional occupation when the ranks are swollen too far, but the attitude and general cultural background of the present-day scientist contrast noticeably with those of the typical scientist of earlier centuries. It was no mere coincidence that the leaders of the golden age of science which began with the *Principia* and ended with the discovery of radioactivity were men of wide culture (in the best sense of that unfortunate word), not only trained to sift truth from error and to fit facts into the pattern of natural laws, but endowed with scholarship and not unfamiliar with the arts. A return by modern men of science to the more liberal training and outlook of former days might well be to their advantage, and the advantage of their work.

In this issue we publish an article by Professor T. A. Stephenson which admirably exemplifies one direction in which the arts may lend assistance to science. The author's combination of scientific knowledge and artistic ability enables him to convey an impression of coral reefs at once accurate and vivid, intellectually satisfying and aesthetically compelling. Such an impression could not be given by any mere written account, however detailed. A statement of the species and varieties, their distribution, their colour, and so on would doubtless be sufficient for many purposes, but no account of natural objects or phenomena that ignores aesthetic values can claim to be comprehensive. Beauty is a stimulus to thought and imagination; its critical appreciation is part of the liberal education with which scientists should certainly be equipped but which they far too frequently lack.

There are admittedly many difficulties in providing scientists with such a desirably broader

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education. The scientist of independent means, able to pursue his studies for their own sake, is today a rarity and has given place to the professional scientist. The very expansion of science makes increasingly difficult the acquisition of those cultural attainments which were so closely linked with its early success, and the professional scientist usually feels it necessary to devote all, or practically all, his energy and attention to his scientific work. There is also an ever-increasing tendency to specialization, and already the subdivision of science into the familiar branches of physics, chemistry, biology, geology, and so forth is proving inadequate. Studies of much more limited scope, such as biochemistry or nuclear physics or mycology, provide ample fields of research for even the most accomplished investigators. The specialist has been defined as a man who knows more and more about less and less, and it is indisputable that before the young research worker can venture out on his own he must acquire, or at least know where to find, a very great amount of knowledge of work already done in his chosen field. In most instances, economic reasons make it essential that this preliminary discipline be completed as quickly as possible; it is therefore almost always impracticable for the science student to devote a year, or even so much as a single term, to studies other than those of immediate professional use.

As the time available for cultural learning is thus so severely and perhaps inevitably limited, it is highly desirable that the science student should be actively encouraged to make the best possible use of what time he has. The mere provision of opportunity is not sufficient: there should be greater effort on the part of the authorities to ensure that it is not neglected.

In certain universities it is, or used to be until quite recently, the custom for arts students to read at least one science subject. The scheme is an excellent one, and *mutatis mutandis* might well be adopted for science students. The trouble with university science is that it turns out men qualified to follow a scientific career but rarely fitted for anything else. The man who reads classics or history or philosophy is not similarly limited, and in fact does not usually become a professional classicist, historian, or philosopher. Would not the ideal university science education leave its graduates an equal freedom of choice? And would not this in the long run prove beneficial to science, to the individual, and to the whole community?

It should be remembered that the intensive specialization of university courses affects not only the subsequent but also the precedent career of the scientist, for the schools feeding the universities have in practice if not in theory to meet the university demands as to the standard of knowledge required for matriculation. In consequence, the boy or girl intending to read science at the university has to begin to specialize two or three years before leaving school, and the narrowness of outlook is likely to have become fixed even earlier than university days.

There is obviously a problem here, and no simple solution presents itself. Perhaps several partial solutions are more promising things to aim at than a single comprehensive one. For example, far more use could be made of the cultural value of science itself by including work on the history of science or the philosophy of science, or both, as an integral part of the curriculum for a degree. The history of science is worth pursuing for its own sake and can in addition prove of the utmost practical value. It is significant that the majority of those scientists who have made fundamental contributions to scientific knowledge have been assiduous students of the history of science. Yet comparatively few universities give any official time at all to the history or philosophy of science.

In a scientific journal it is not necessary to expatiate on the desirability of the steady advancement of science. It is, however, necessary to take stock of the position from time to time, and at the present moment we may usefully ask ourselves whether the prevailing tendency to closer and closer specialization possesses sufficient merits to outweigh its very apparent demerits. The progress of science has depended upon the existence of men able to think in the broadest terms and to perceive unity in diversity. Such men cannot be nurtured on science alone; much less can they prosper in a parochial area of science.

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Migration of vertebrate animals

J. GRAY

Although the phenomenon of migration has long excited curiosity, it is only in comparatively recent years that it has received the detailed investigation it deserves. Painstaking research has established the main facts relating to the migrations of many vertebrate types, but the interpretation of the facts there collected, in regard both to the reasons for migration and to the means by which the long journeys involved are successfully made and retraced, is still uncertain. In this article Professor Gray summarizes the tendency of current opinion.

Among vertebrate animals, long-ranged cyclical movements are particularly characteristic of aquatic and aerial forms—fish, birds, seals, whales, and some bats. In every case they raise two fundamental problems: (i) What determines the time, direction, and extent of an outward journey towards what is, almost invariably, a breeding site? and (ii) Why and how does the animal or its offspring forsake its breeding site and return to its original starting-point? The following survey of the migratory activity of certain vertebrate types may serve to indicate the drift of current opinion.

Among fish, classical examples of long-range migration are provided by the eel and salmon; less spectacular but none the less significant movements are, however, carried out by such forms as the cod and many other fish which form the basis of important industries. Cod (*Gadus morrhua*) are distributed in the sea in large shoals, each of which behaves as a more or less independent entity. The main feeding ground of one of the most important of these aggregations lies in the relatively shallow cold waters in the region of Spitsbergen, Bear Island, and the Barents Sea: here the young fish spend their early years growing rapidly on abundant plankton. After eight years they become sexually mature and migrate to the west coast of Norway to form dense spawning shoals in the neighbourhood of the Lofoten Islands. There the eggs develop, and in due course the resultant larvae drift passively northwards in the prevailing currents, the spent fish moving more slowly in the same direction. Eventually, both parents and young fish return to the feeding grounds. The cold northern waters are essentially feeding areas rich in plankton, while the warmer waters of the spawning ground permit the eggs to develop at a rate which is presumably sufficient to enable the young fish to feed by the time they have been carried passively to a suitable 'nursery' feeding ground. As has been pointed out by Dr E. S. Russell, this and other instances of fish migration conform to the rule that the active mature fish swim against the prevailing current before depositing their eggs, while the eggs and larvae are carried passively by the current towards an appropriate nursery. It must be borne in mind, however, that a constant current cannot provide a fish with any direct clue concerning its position relative to the ground; it is only when a fish is receiving visual or other types of stimulation from a fixed object (e.g. by swimming near the sea floor) that it can control its movements relative to the earth. On the other hand, a mass of water having specific temperature or salinity gradients might well provide an effective means of navigation, since fish can detect such gradients with an extremely fine degree of precision.

A similar passive drift of fish larvae towards the feeding grounds is illustrated by the eastward movement, across the Atlantic, of the larvae of the European eel; we can, however, only speculate how far the upstream migration of the elvers into fresh water depends on hydrographical factors. Similarly, we can only conjecture how far the westward migration of the adult eels, when once these have reached the sea, is essentially a steady progression into deeper and deeper water, or how far it is dependent on the passive action of oceanic currents. It is, however, in the case of the salmon that the migration of fish seems to reach its most perplexing form, for within recent years the general trend of the evidence is towards the belief that the adult fish shows a marked tendency to return to the stream in which it has previously spent its early years as a smolt. The evidence in support of this remarkable conclusion is largely derived from observations on the various species of the Pacific Salmon (*Onchorhynchus*) in the United States and Canada. In 1929 Rich and Holmes showed that the adult King Salmon

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(*O. twchawytcha*) which enter the main Columbia River do so in two main runs, one in spring and the other in autumn. Those which enter in spring pass upstream for nearly a hundred miles and then turn southward into the Willamette River; those which enter in the autumn move continuously east into the upper reaches of the Columbia. By marking large numbers of smolts before their descent to the sea, two important conclusions were reached. (i) Fish which have developed in the Willamette and Columbia, respectively, return to their original rivers. A very surprisingly large percentage of the recaptured fish are recovered from very small tributary streams from which some of the total stock of marked smolts had originally been derived. (ii) Fish which have developed from eggs derived from Willamette fish, but which have been hatched and reared in the upper Columbia, return as adults to the latter river, although at the time of the year characteristic of the run into the Willamette. Comparable 'homing' phenomena were observed by Davidson in the Pink Salmon (*O. gorbuscha*) and by Foerster in *O. nerka*. In the latter case, smolts were marked and replaced into the Cultus River, a small tributary of the Fraser: out of a total of 967 recaptured adult fish, 83 per cent. were taken in the Cultus river, the remaining 17 per cent. in the fishery grounds at sea, and none from any other spawning ground. These results suggest that when in fresh water the young fish have a very definite topographical sense, based conceivably on patterns of water temperature, oxygenation, or chemical composition; they suggest too that the fish 'remember' these patterns and associate them with the proximity of a specific spawning ground. These conclusions are sufficiently important to warrant the exercise of considerable caution before regarding them as fully established principles of fish behaviour. It must be borne in mind that we have, as yet, very little precise knowledge concerning the extent or direction of the movements carried out in the sea by fish which have returned to their original spawning ground. So far, our knowledge appears to be restricted to data derived from two individual fish (*O. gorbuscha*) which were marked as fry by Pritchard at Morrison Creek, Vancouver Island. One of these fish was caught on 19th August, 1943, at Deep Water Bay, Johnstone Strait (forty-five miles north of Morrison Creek) and retaken at Morrison Creek on 6th October; the other fish was caught on 30th August, 1943, off Lopez Island, Puget Sound (115 miles south of Morrison Creek) and retaken at Morrison Creek on 6th October. The evidence certainly suggests that this species of *Onchorhynchus* travels for relatively long distances beyond the mouths of its rivers of origin, and has, during its return journey, opportunities of entering spawning streams other than its own. On the other hand, until these two points have been thoroughly investigated, our general picture of 'homing' ability in fish must remain liable to revision. The need for further inquiry seems emphasized by what is known of the movements of the Atlantic Salmon (*Salmo salar*) on the eastern seaboard of Canada. Huntsman concluded that those smolts which return to their river of origin do not proceed to sea for distances far beyond the zone over which the outflow of their parent river can exert a physical or chemical influence, and consequently an inshore migration automatically brings them to the vicinity of their own river; fish which migrate for long distances have not, as yet, been proved to return. Again, the accuracy of the 'homing' migration in *Onchorhynchus* appears to vary with the number of alternative spawning sites available to the returning fish; if only one site provides the physical requirements of an effective spawning ground the concept of 'memory' seems no longer necessary, since the site could be found by random exploration. In contradistinction to the conclusion reached by Rich and Holmes for the Pacific Salmon, White and Huntsman concluded that the 'autumn' or 'spring' running habit of the Atlantic Salmon is determined by the nature of the stream in which the smolts develop and not on the genetical constitution of the fish. In the case of British salmon, there is some circumstantial evidence in favour of 'homing' activity, and it is to be hoped that much-needed further investigations will not be long delayed. Such investigations should not be restricted to a detailed study of the physiology and movement of the fish, but should include a very careful hydrographical survey of the waters through which they migrate.

Migratory activity at the breeding season is common among amphibia, and similar movements occur among amphibious reptiles, but in no case do these migrations appear to approximate in magnitude to those of fish or birds. Wide as is the evolutionary gap between the last two classes of vertebrates, the main features of their migrations seem curiously similar: in all cases the movements are keyed into cycles of reproductive or nutritional activity. The migratory cycle of birds, however, is more closely linked with

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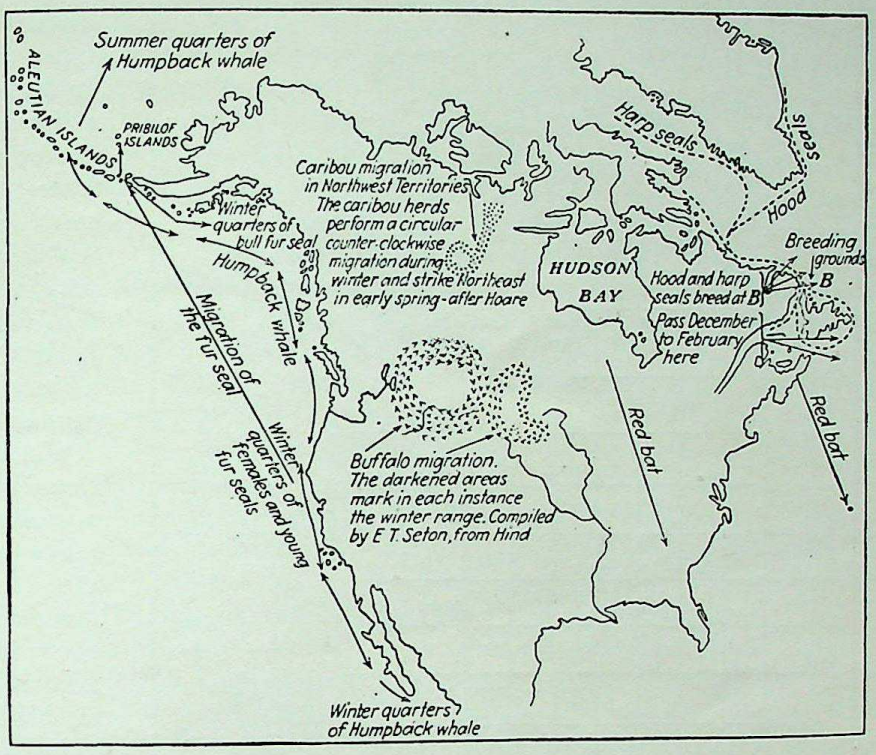

FIGURE 1 – The Migration Routes of Several North American Species. *Whales of several species summer in the Arctic seas and spend the winter months off the coast of lower California. The winter quarters of migratory bats are not well known, but they have been taken on ships far at sea and on Bermuda.*

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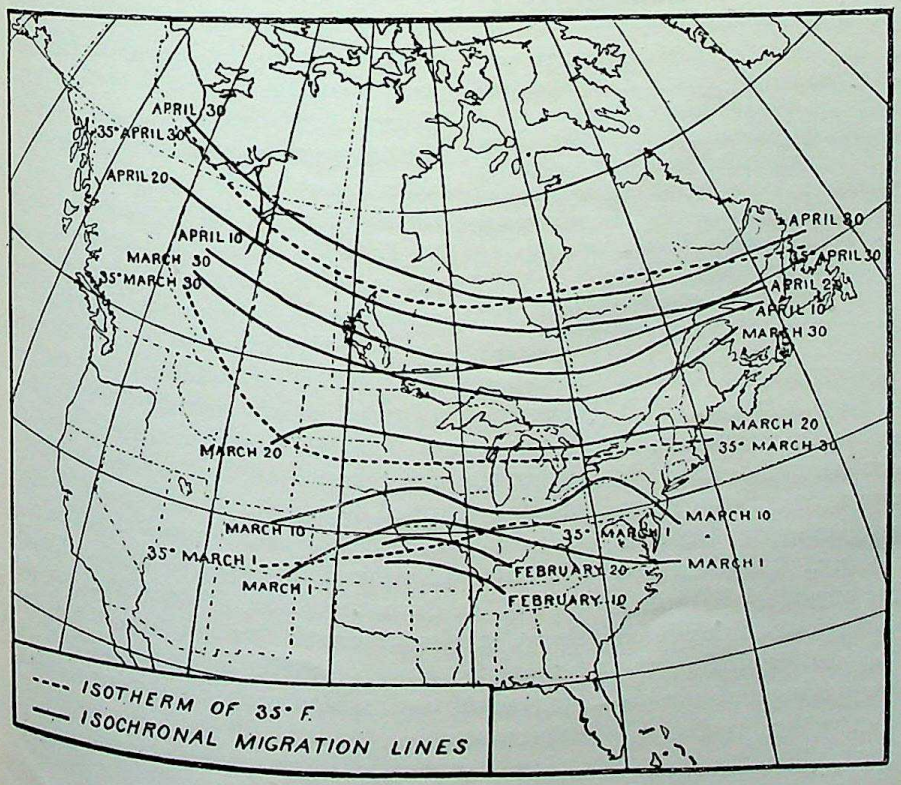

FIGURE 2 – Migration of the Canada Goose. *The northward movement keeps pace with the advance of spring, in this case the advance of the isotherm of 35° F. agreeing with that of the birds.*

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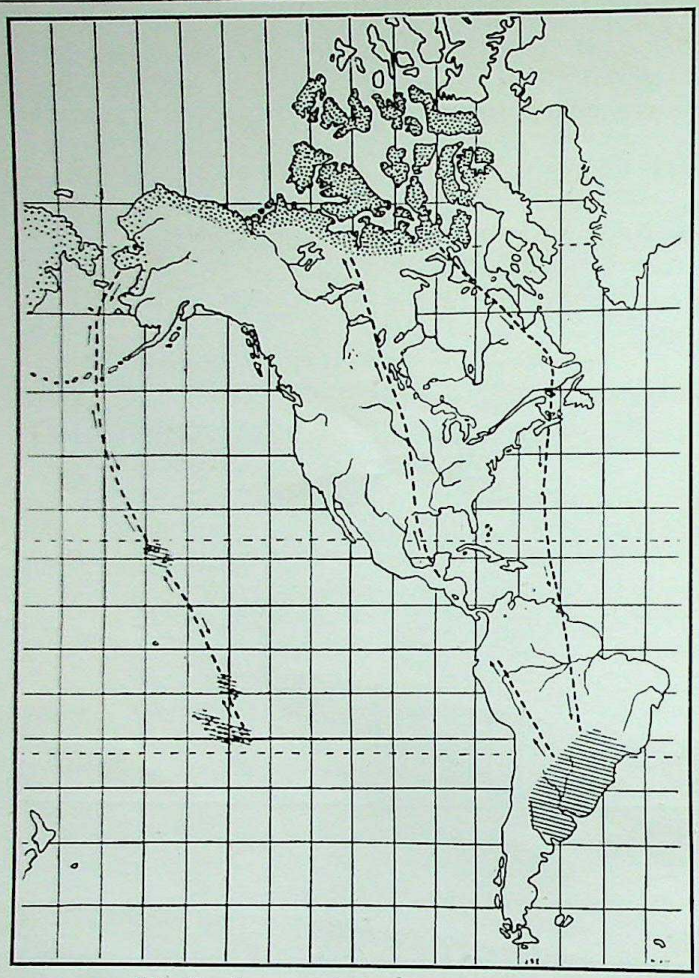

FIGURE 3 – Distribution and Migration of the Golden Plover, Charadrius dominicus. *Adults of the eastern form* (Ch. dominicus) *migrate across north-eastern Canada and then by a non-stop flight reach South America. In spring they return by way of the Mississippi Valley. Their entire route is therefore in the form of a great ellipse with a major axis of* 8,000 *miles and a minor axis of about* 2,000 *miles. The Pacific golden plovers* (Ch. fulvus), *which breed in Alaska, apparently make a non-stop flight across the ocean to Hawaii, the Marquesas Islands, and the Low Archipelago, returning in spring over the same route.*

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annual cycles of seasonal change than is that of fish. Birds resident in the tropics may exhibit definite migratory phenomena in response to local conditions, but it is essentially in those which extend their breeding range to temperate or arctic zones that the most striking and extensive patterns of migration are found to occur. It is therefore reasonable to assume that the migratory habit has been impressed upon the behaviour of the birds by climatic factors operating either during the past history of the species or during the lifetime of existing individuals. It must be frankly admitted, however, that the available facts do not readily fit into any simple or convincing picture. In broad outline the migratory movement in the northern hemisphere is towards the north in spring and to the south in autumn. In this way the bird avoids the rigours of the northern winter while enjoying the long hours of the northern summer when rearing its young. In each species, the northern movement occurs within reasonably constant dates each year, and it has long been suspected that either an increasing period of daylight or an increase in mean daily or nightly temperature may be the operative factor. Rowan showed that artificial variation in the period of illumination of juncos and crows had a profound effect on the rate of maturation of the ovary and testis, and at the same time affected migratory activity. The state of the gonads as controlled by light cannot, however, account for the northern migration of birds which winter within the tropics, or of young birds (e.g. those of the gannet) which migrate northwards before they are sexually mature. Further it is difficult to see how light can be an operative factor in cases where the spring migration is essentially from west to east, as appears to be the case with starlings nesting in northern Germany. Kendeigh's observations on the eastern house-wren (*Troglodytes aedon aedon*) suggest that migration is regulated more by temperature than by light; in spring and early summer the birds tend to move away from regions of unduly high daily temperature, but eventually the northward movement is checked at latitudes where the high rate of metabolism required to protect them against low night temperatures can no longer be fully sustained by the food which can be consumed during the day. This view seems to be supported by the observations that the rate of northward migration follows reasonably closely that of an isothermal line, which varies for different species. Nevertheless it is difficult to see how such changes in diurnal temperatures can operate on birds which winter within or south of the tropics.

Just as it is difficult to say why a migrating bird

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leaves its winter quarters, so it is difficult to demonstrate the factor which urges it to leave its nesting area. In extreme cases the decreasing period of diurnal feeding may well operate with decreasing nightly temperature to produce conditions from which the birds must either migrate or die, but the facts do not suggest that such things are always the primary or dominating factors. Even within the range of a single species, the period of migration away from the nesting site for some individuals overlaps the period of reverse migration in other individuals. Similarly, many cases are known where only part of a population exhibits migratory movements: some individuals remain resident, while others migrate. The most satisfying picture of a typical migratory cycle is probably that provided by Thomson, who suggests that it is essentially an expression of an inherent genetical rhythm of metabolic change or behaviour-pattern whose onset can be accelerated or delayed by environmental factors. This conception accounts for the migratory activity of birds wintering in the tropics but implies the inheritance of a mechanism which responds to an extraneous environmental factor in such a way as to limit the bird's movement to a particular direction. Valuable information concerning the nature of this factor might be forthcoming from a careful study of the extent to which climatic factors form definite gradients within the range of the bird's daily non-migrational movements, and of the extent to which the detection of these gradients falls within the limits of the bird's sensory perception at various phases of its reproductive cycle. As will be shown later, however, the power of a bird to return to its home after passive transportation is not always restricted to the direction characteristic of its seasonal migration. It must also be remembered that closely related species of birds may display very different levels of migratory activity.

The existence of an extraneous factor which limits the bird's movement to a particular direction represents one of the most interesting but perplexing of all biological phenomena. How does the bird control the direction of its migratory flight, and, above all, how does it return many months later to its starting-point after a journey of many hundreds or thousands of miles? These questions must remain unanswered until we possess more accurate and complete knowledge concerning the direction of flight during the whole of the migratory cycle. Roughly speaking, there are two main types of theory: (i) Those which postulate the existense of sensory clues whereby the bird navigates towards a specific goal. (ii) Those which regard the bird's return as the result of more or less systematic exploration unaided by sensory guides. In the case of relatively short-ranged movements there can be little doubt that visual clues play an important if not exclusive role. During its outward flight the bird almost certainly orientates its movement by reference to conspicuous features on the ground, seeking meanwhile for a suitable nesting site; during the return flight to its winter home the bird 'remembers' these landmarks and navigates accordingly.

Most of the older charts of migratory routes support the view that migrant birds follow a definite 'flight line' marked out by distinctive features of the landscape—coastlines, river valleys,

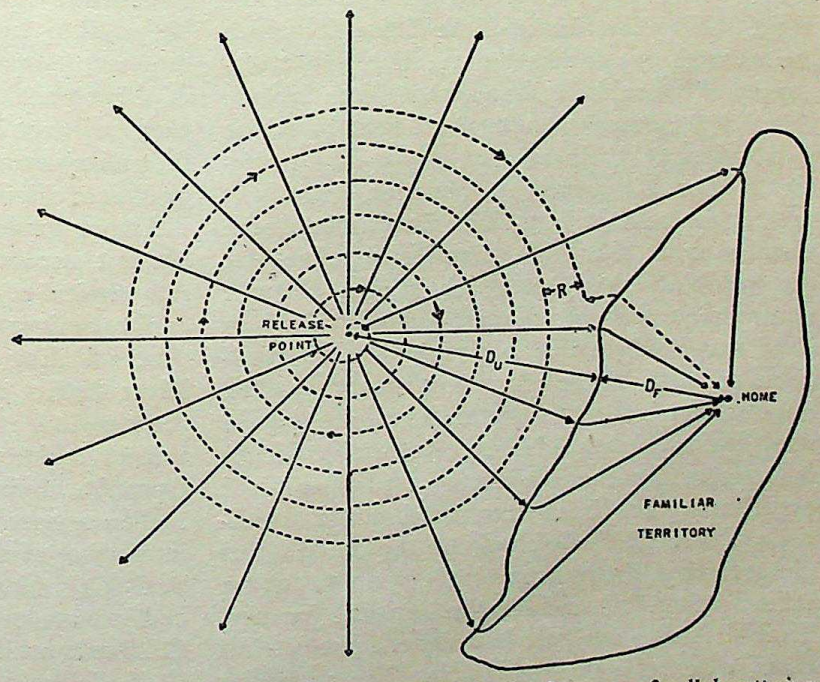

FIGURE 4 – *Hypothetical flight paths of birds homing by means of radial scattering (solid lines) and spiral exploration (dotted lines). In this diagrammatic instance five out of sixteen birds reached home by means of radial scattering, flying courses* 1·03, 1·04, 1·18, 1·67, *and* 1·7 *times the straight-line distance* $D_F + D_U$. *The bird homing by spiral exploration would have flown approximately* 13·3 *times the straight-line distance.* (*Reproduced by courtesy of the* Quarterly Review of Biology.)

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short sea routes, and mountain ranges. It is, however, obvious that visual methods of navigation cannot account for certain well-established facts. Firstly, the range from which some species can home successfully is far beyond that over which they can be reasonably expected to have had previous visual experience. Starlings have returned from Berlin to almost all parts of Germany after forced journeys varying from twenty-five to nearly four hundred miles; ducks bred in Louisiana have returned from the Pacific and Atlantic seaboards of the United States; shearwaters native to South Wales have returned from Venice. Secondly, many of the most spectacular migrations involve long and continuous flights over the sea far away from land; the Bronze Cuckoo (*Calcites lucidus*) winters in the Solomon Islands, and its flight to its breeding area in New Zealand involves a transoceanic flight of at least nine hundred miles. Thirdly, the weight of recent evidence tends to support the view that migration often occurs over a broad front, and that the course followed on the homeward journey may differ very considerably from that of the outward journey. According to Moreau, the migration of the White Stork (*Ciconia ciconia*) across Egypt occurs over a front of six hundred miles, and many of the birds must be far outside visual range of such navigational features as the Nile Valley. Many of the difficulties which beset the theory of visual navigation might disappear if it could be shown that birds include celestial phenomena in the visual field by which they orientate their normal day-to-day movements. For this suggestion, however, there is at present no basis of fact. The limitations of the visual sense as a basis for aerial navigation raise the possibility that sensory clues of a different nature are employed. Exner, Meise, and others have suggested that a bird may use its semicircular canals or the proprioceptor organs of its muscles and joints to register deflections from a straight-line flight. The experimental evidence is, however, far from convincing, and none of the experiments has been conducted under conditions which effectively eliminate the use of visual clues; further, the return route is by no means the same as that followed on the outward journey. That birds may navigate by magnetic or electrical clues is exceedingly improbable. There remains the possibility that 'homing' is effected, not by means of definite sensory navigation, but by organized exploration. Theories of this type include the spiral type of flight advocated by Hodge for homing pigeons: a bird is presumed to fly along a spiral path of ever-increasing radius until it inevitably comes in sight of known territory. It is almost inconceivable that such a procedure would enable a bird to return from a point many thousands of miles away from its goal. Less unconvincing, perhaps, is the suggestion of Claparede, whereby a bird is assumed to fly along a straight line, whose direction is determined by chance. On this basis the number of individual birds which would reach their 'goal' would vary inversely with the distance to be flown and directly with the size of the territory previously known to the bird. Griffin has shown that the data available from birds artificially removed from their natural locality conform to this general rule. Unfortunately, there is considerable doubt concerning the extent of territory over which a bird can or does range during the non-migratory phases of its life. At the same time it hardly seems possible that a serious element of chance is involved in the case of an individual migrant returning from many hundreds of miles to the same nesting site for two years in succession, or in the movements of the Golden Plover (*Charadrius fulvus*) between Alaska and Hawaii. It seems strange that we are unable to assess the significance of sensory navigation as opposed to that of non-directional exploration. A decisive test ought to be possible by anaesthetizing birds during the outward journey; unfortunately, all experiments of this type have so far been inconclusive, since they have not been done under conditions which fully eliminate the possibilities of visual navigation or chance discovery.

Among terrestrial mammals seasonal migrations are not uncommon, especially in sub-arctic and sub-tropical regions. In North America elk and caribou migrate in large herds towards definite winter feeding grounds; similarly, in the Orange River district of Africa the springbok migrate at the breeding season to the rich vegetation of the upland regions. It is, however, among aquatic types that the most spectacular instances of mammalian seasonal migration occur. One of the most interesting of these movements is that of the Fur Seal (*Callorhinus alascanus*), in which the females and immature males winter as far south as Southern California while the mature males winter in the Gulf of Alaska or near the Aleutian Islands. At the breeding season the mature males migrate northwards to the Pribilof Islands—small rocky islands north of the Aleutians and two hundred miles from the nearest land. At this small isolated breeding ground the females also foregather after a

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journey of three thousand miles, which is said to be effected on a 'true course.' These females are pregnant and give birth to their young within a few days of their arrival; soon after weaning their young they are again impregnated and set out on their southerly migration. Although different in some respects, the general cycle raises the same essential problems as those raised by migratory birds. In both cases the mechanism which controls the direction of the movements is quite obscure, and is likely to remain so until a great deal more is known of the physical properties of the medium through which the movement occurs and of the extent to which the animal's sensory equipment enables it to detect very slight changes in these properties. At the same time it must be remembered that accurate observation of the precise movements of an individual bird or a whale over a considerable period of time is extremely difficult; we have, therefore, to rely on data which are liable to a good deal of statistical error—it is very easy to attribute undue significance to isolated observations. The same difficulties arise in attempting to assess the homing ability of dogs. Popular literature is rich in accounts of dogs returning to their homes after transportation for long distances; we must not forget, however, the frequency of advertisements for lost dogs. In view of its intrinsic interest it is strange to find that very few attempts have been made to approach the problem from a scientific angle. Adequately controlled experiments would be difficult, but by no means impracticable.

In addition to seasonal or reproductive migrations, some mammals exhibit marked 'emigrational' outbursts which occur at relatively irregular intervals. Of these the lemming is the classical example. This small rodent lives in colonies in the barren arctic steppe country of eastern Scandinavia. It normally breeds twice a year and has four or five young in a litter. At somewhat irregular intervals (2–4 years) the population of lemmings is built up to a very high level—possibly owing to increase in fertility. When this occurs, almost the entire population begins to move down the western valleys which radiate downwards from the mountainous plateau. This process goes on progressively until the lemmings enter the sea and are eventually drowned. The facts as recorded by Collett seem to establish five points with tolerable certainty:

(i) The migration is dependent on the existence of an abnormally high level of population density.

(ii) It is not directly due to lack of food or other ecological factors—a limited number of lemmings remain resident in their original haunts, and from these a new population is built up.

(iii) The migration does not increase the permanent zone of distribution of the species.

(iv) The vast majority of emigrants perish.

(v) Migration involves a change in the physiological state of the animal, rendering a shy, timid creature relatively bold, if not pugnacious.

The general picture of the whole phenomenon can be regarded as 'a rather tragic procession of refugees, with all the obsessed behaviour of the unwanted stranger in a populous land, going blindly on to various deaths' (Elton). Closely similar to this remarkable migration are the mass movements of springbok and other game at cycles varying from ten to twenty years. These have been described by Heape and other writers. Vast numbers of animals, forming wide continuous columns, migrate westward for many days on end. Countless numbers die on the way, but eventually the remainder reach the sea, where they too perish. From such great movements there is no return.

Unidirectional migration is not restricted to mammals. Pallas's Sandgrouse (*Syrrhaptes paradoxus*) is normally resident in eastern Europe and central Asia, with rare stragglers in western Europe. In 1863, and still more in 1888, however, large numbers appeared over the whole east coast of Britain and spread over the whole of the British Isles. Comparable but perhaps less spectacular 'invasions' by other species are known. It is just possible that these phenomena may be associated with particular environmental conditions, but it seems more likely that they represent a response on the part of a population which has, for one reason or another, suddenly reached a magnitude far beyond that which can be supported by its normal range of territory. In this respect they appear to be related to the spasmodic migration of locusts, where the migratory habit seems fairly clearly associated with population density and thus with circumstances which appear to be conducive to a gregarious existence.

A review of the available evidence makes it fairly clear that each of the main problems raised by migrating animals still remains unsolved; at the same time there seems no reason to believe that they are insoluble.

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The Imperial College of Science and Technology

H. J. T. ELLINGHAM

The Imperial College of Science and Technology resulted from the fusion of several previously existing institutions, of which the oldest was founded just over a century ago. It is perhaps to this multiple origin that the College owes the cosmopolitan outlook which has done so much to establish its present world-wide reputation. In this authoritative article Dr Ellingham gives a clear account of the rather involved early history of the College, and of the many eminent scientists who have been associated with it as graduates or teachers.

The Imperial College of Science and Technology, constituted by Royal Charter in 1907, is a federation of three institutions that had previously become established at South Kensington. The youngest of these, the City and Guilds College, was founded there in 1884 as the Central Institution of the City and Guilds of London Institute. The other two, the Royal School of Mines and the Royal College of Science, have longer and more complex histories extending back to a common ancestor, the 'Government School of Mines and of Science applied to the Arts,' which was established in the Museum of Practical Geology, Jermyn Street, in 1851. The Chemistry Department of the Royal College of Science, however, originated in a still earlier foundation, the 'College of Chemistry,' which was opened in George Street, Hanover Square, in October 1845.

In the second quarter of the last century there occurred a gradual awakening to the importance of science for the more effective utilization of the natural resources of the country. In 1834 Henry Thomas de la Beche persuaded the Government to establish the Geological Survey of the British Isles, and, as the first director of this new department, he was active in building up a Museum of Economic Geology in Craig's Court, adjoining Scotland Yard, where a limited number of pupils was received for instruction in mineralogy, metallurgy, and analytical chemistry. In 1842 a group of private persons put forward a scheme for the foundation of a school of practical chemistry which they proposed to name after Sir Humphry Davy. An application to the Royal Institution for accommodation for the proposed school was rejected on the ground of lack of space, but the enthusiasm of the promoters of the scheme, among whom was de la Beche, was not damped. At a public meeting held in St. Martin's Place on 29th July, 1845, definite form was given to the proposed College of Chemistry and a council was elected of which Prince Albert consented to be president. Through the personal intervention of the Prince, August Wilhelm von Hofmann, then *Privatdozent* at Bonn, was enabled to accept the professorship.

Temporary laboratories were fitted up in a house in George Street, and the College—the first organized school of practical chemistry in England—was opened to students in October 1845. In December, Queen Victoria permitted the new institution to be named the 'Royal College of Chemistry,' and in the following year permanent quarters were obtained in a specially erected building at 299 Oxford Street. The available accommodation—eventually for about fifty students—was soon taken up by 'men of all ages, of all ranks, and of a variety of professions—gentlemen following chemistry as a profession or as an object of scientific taste, chemists and druggists, medical students and medical men in practice, officers in the Army, clergymen, agriculturists, manufacturers in almost all branches of the chemical arts.' Among those who passed through Hofmann's hands were many who subsequently exercised a dominant influence on the development of science and industry. The first five years of the College produced Sir Frederick Abel, Sir William Crookes, Sir Edward Frankland, Warren de la Rue, William Odling, Frederick Field (who developed copper-smelting in Chile), F. W. Pavy (a pioneer in the study of diabetes), Frederick Dyson Perrins (pharmaceutical chemist), and Henry Condy (chemical manufacturer). In the next five years there emerged Edward Divers, Herbert McLeod, and Sir William Perkin, the last of whom made his discovery of the first artificial dye in 1856 while he was a research assistant in the College.

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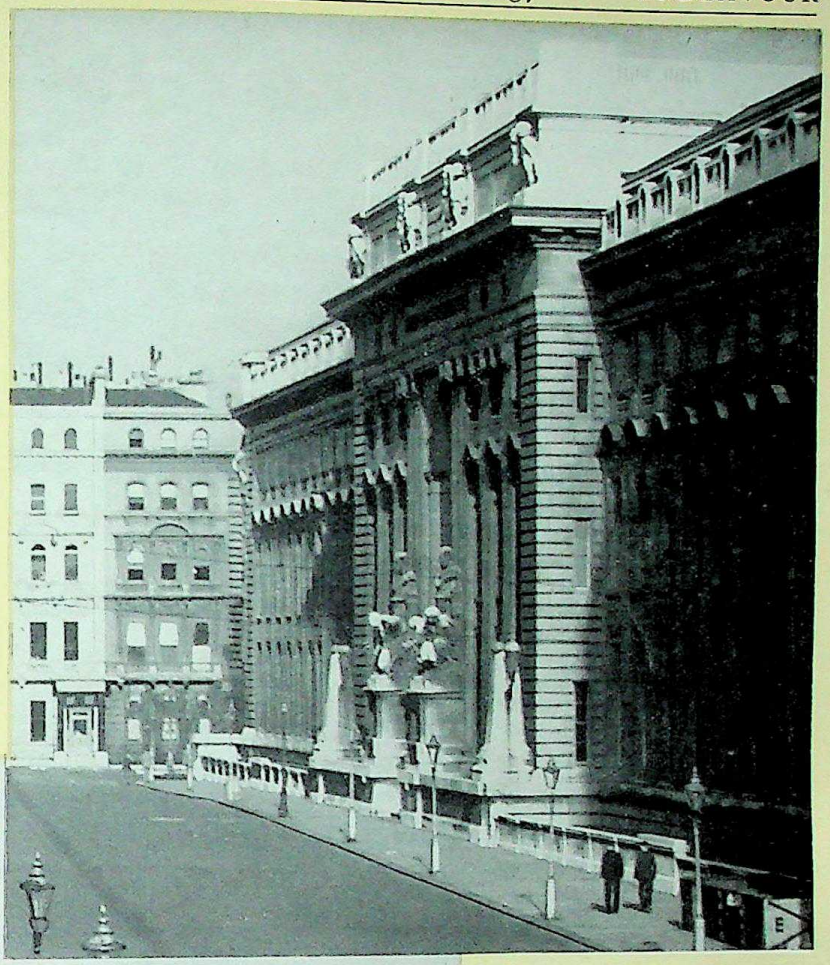

FIGURE 1 – *Royal School of Mines, Prince Consort Road, South Kensington.*

FIGURE 2 – *City and Guilds College, Exhibition Road, South Kensington.*

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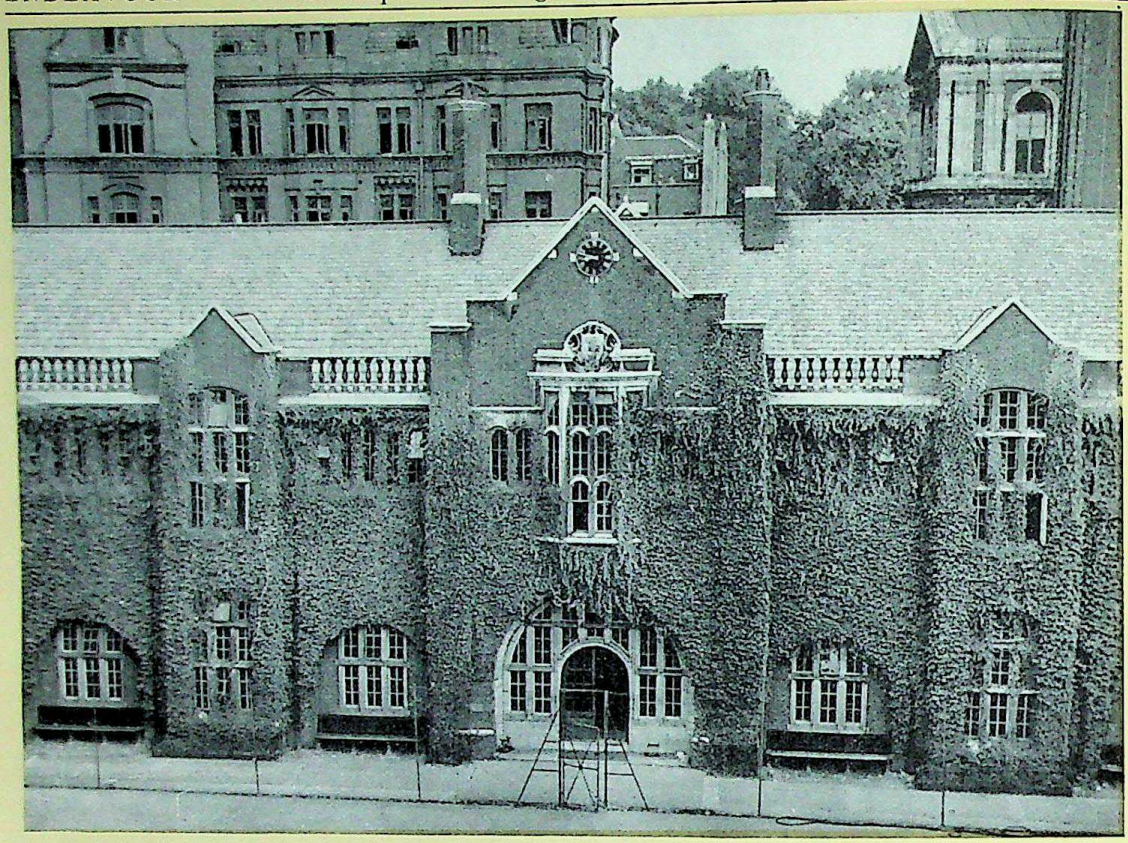

FIGURE 3 (*above*) – *Imperial College Union, Prince Consort Road, South Kensington.*

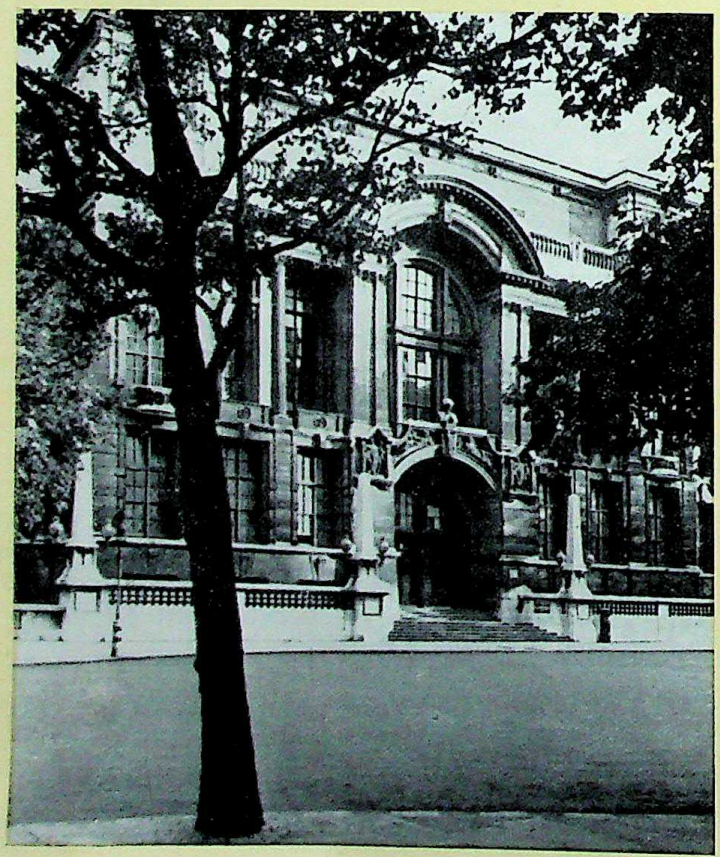

FIGURE 4 (*left*) – *Royal College of Science. Departments of Chemistry and Physics, Imperial Institute Road, South Kensington.*

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In 1851 (the year of the Great Exhibition in Hyde Park) the Government provided new accommodation in Jermyn Street for the Geological Survey and Museum, and de la Beche was enabled to put into effect his long-harboured plan for using the resources of the Museum as a basis for organized courses in mining and applied science. The Government School of Mines and of Science applied to the Arts was opened on 6th November, 1851. Its staff, which was drawn from that of the Survey, comprised Warington Smyth (Mining and Mineralogy); Andrew Ramsay (Geology); John Percy, who later came to be known as 'the father of English metallurgy'; Robert Hunt (Mechanical Science); Edward Forbes (Natural History applied to Geology and the Arts); and Lyon (afterwards Lord) Playfair (Chemistry applied to the Arts and Agriculture). It was subsequently said of this remarkable team: 'Rarely in any country, probably never in England, was a more brilliant and gifted staff brought together for teaching purposes than those who, under Sir Henry de la Beche, established a mining school in London, 1851.'

Two categories of students were received at the school: 'associate' students, who took the full-time professional mining course leading to the diploma of associateship of the school, and 'occasional' students, comprising at first 'chiefly soldiers, a few ladies and philosophers . . . and pupils of the School of Design,' who took only selected parts of the course or lectures in a particular subject. The latter were the more numerous, but it was on the former that the reputation of the school was based. As de la Beche's successor, Sir Roderick Impey Murchison, remarked, 'I view it simply as the school of British geology and mines: the affiliated sciences are all subordinate to that fundamental point.' The Prince Consort, however, hoped to see the school develop into 'a Government educational establishment for the diffusion of science generally, as applied to productive industry,' and the newly formed Science and Art Department of the Board of Trade pressed for a widening of the scope of the instruction to this end. Through their efforts the name of the institution was altered in 1853 to the 'Metropolitan School of Science applied to Mining and the Arts,' but the change was more apparent than real, for there was in fact neither money nor accommodation to provide for the proposed extension of activities. The professors realized this, and although some, like Thomas Henry Huxley (who had succeeded Forbes as Professor of Biology in 1854), were supporters of the wider view, they were not prepared to endanger the development of the associateship course by merging it in a general school of applied science. Murchison harnessed the forces of reaction and managed to get the name of the institution changed in 1857 to the 'Government School of Mines,' and finally, in 1863, to the 'Royal School of Mines.' The title of the diploma was altered—retrospectively—to 'Associate of the Royal School of Mines' (A.R.S.M.). The output of associates was never large, but included in the period from 1851 to 1872 men such as Hilary Bauerman, H. F. and W. T. Blanford, Sir Clement LeNeve Foster, Benjamin Peach, George M. Dawson, Percy Carlyle Gilchrist, William Gowland, Hugh Miller, and Sir William Chandler Roberts-Austen—men who subsequently played leading parts in the advancement of science and its application to the development of the mineral resources of the world.

Throughout this period, however, laboratory facilities for the study of the 'other sciences,' especially biology (under Huxley) and physics (successively under Sir George Stokes and John Tyndall, as visiting professors), were almost entirely lacking. That the position was different in chemistry arose from the fact that when Playfair left the school in 1853 the laboratories of the Royal College of Chemistry in Oxford Street had been taken over by the Government, and the College 'incorporated' with the Jermyn Street institution as its Chemistry Department, with Hofmann as professor. By this arrangement the place of practical chemistry in the mining school course was assured. Moreover, the Royal College of Chemistry, thereby relieved of financial difficulties that had arisen through its dependence on private funds, retained a considerable measure of autonomy as a school of chemistry, and under Hofmann and his successor, Sir Edward Frankland, continued until 1872 to enrol its own students and to bestow its own Associateship. Among its alumni in the 'sixties were Sir William Tilden, Lord Shuttleworth, H. E. Armstrong, A. S. Herschel, J. A. R. Newlands, and Sir Alexander Pedler.

In 1870 a Royal Commission recommended that the Royal School of Mines be removed to South Kensington and there consolidated with the Royal College of Chemistry. This proposal, involving the separation of the mining school course from the Museum, was strongly resisted by Murchison, Warington Smyth, and Percy, but it

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had to be recognized that if instruction in the other sciences was to be effectively developed, as Huxley demanded, the necessary accommodation would have to be found elsewhere. The Government had acquired, some years previously, from the Commissioners of the 1851 Exhibition, about twelve acres of land at South Kensington for the use of the Science and Art Department, and it was on this site that the departments of Biology (Huxley), Physics (Guthrie), and Applied Mechanics (Goodeve)—from Jermyn Street, and Chemistry (Frankland)—from Oxford Street, were rehoused in 1872. The quasi-independent existence of the Royal College of Chemistry thus came to an end; the building in Oxford Street passed into other hands and was subsequently demolished.

The displaced departments were accommodated in a highly ornamented building in the Italian style in Exhibition Road; now known as the 'Huxley Building,' it is still occupied by departments of the Imperial College. No longer subservient to the mining school course, the departments of the Royal School of Mines at South Kensington soon developed as a separate school of science, and when they were joined in 1877 by the Geology Department it became clear that a new order was emerging. The Committee of Council on Education (the forerunner of the Board) was anxious to see established at South Kensington a school devoted to all branches of applied science with a special organization for the training of science teachers, and was prepared to treat the mining and metallurgy course as a subsidiary feature of this programme. A compromise was reached. In 1881, following the transfer of the Metallurgy Department to South Kensington, the school opened under the composite title of the 'Normal School of Science and Royal School of Mines,' with Huxley as its first dean. Officially it was one school organized in two divisions: the department of Mining (which remained at Jermyn Street until the death of Sir Warington Smyth in 1890) and that of Metallurgy constituting the Royal School of Mines, and the remainder the Normal School of Science—renamed the 'Royal College of Science' in 1891. The two divisions came to be regarded, however, as two associated colleges, each with its own character and traditions and with separate diplomas—A.R.S.M. and A.R.C.S. Among those trained there in the period 1872–1900 were William Frecheville, Sir Charles V. Boys, W. R. Hodgkinson, Henry Louis, E. T. McCarthy, P. F. Frankland, R. D. Oldham, W. H. and A. G. Perkin, Thomas Turner, F. W. Harbord, F. Merricks, J. G. Lawn, S. J. Truscott, W. H. Merrett, S. W. Smith, and L. L. Fermor—at the Royal School of Mines; W. P. Wynne, Alfred Fowler, A. E. H. Tutton, H. G. Wells, F. W. Lanchester, Sir Richard Gregory, Sir Albert Howard, F. C. Lea, W. H. Eccles, Sir Gilbert Morgan, Sir Frank Smith, James Whitehead, Sir Herbert Wright, and L. Bairstow—at the Royal College of Science.

While the Royal College of Science and the Royal School of Mines were emerging in their modern forms, steps were being taken towards the foundation of the other great institution that was to be associated with them. In 1878 the Livery Companies of the City of London created the 'City and Guilds of London Institute for the Advancement of Technical Education.' This body placed in the forefront of its programme the establishment of a 'Central Institution for the advanced education of those who had acquired sufficient knowledge of science or the arts to profit by instruction in the industrial applications of these.' A building for this purpose in Exhibition Road was completed and opened to students in 1884. Although it had been intended that the courses should cover most branches of technology and the decorative arts, the professorships were limited to four in the first instance: Engineering (W. C. Unwin), Chemistry (H. E. Armstrong), Mechanics and Mathematics (Olaus Henrici), and Physics—subsequently Electrical Engineering—(W. E. Ayrton). The diploma of the College (A.C.G.I.) soon became well known in the field of engineering. In 1893 the name of the College was changed to the 'Central Technical College' and in 1907 to the 'City and Guilds College.' Among 'Old Centralians' of the period 1884–1900 the following may be mentioned: Sir Alfred Chatterton, H. A. Humphrey, W. E. Sumpner, E. F. Armstrong, W. du B. Duddell, D. W. Dye, Sir William Pope, C. V. Drysdale, M. J. P. O'Gorman, F. Twyman, Sir Ernest Dowson, and Ralph Freeman.

Since 1884, then, there had existed at South Kensington three institutions devoted to scientific and technological education and research. All were developing rapidly and soon became pressed for accommodation—a pressure which was partly relieved in the Royal College of Science by the provision in 1906 of a new building for chemistry and physics. In the scope of their work the three colleges were largely complementary, and in 1906 a Departmental Committee of the Board of Education put forward a scheme for their closer

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co-ordination: 'The main object is the establishment at South Kensington of an institution or group of associated colleges of science and technology where the highest specialized instruction should be given and where the fullest equipment for the most advanced training and research should be provided in various branches of science, especially in its application to industry.' On 8th July, 1907, the Imperial College of Science and Technology was established by Royal Charter. The Royal College of Science and the Royal School of Mines were transferred forthwith to the Governing Body of the new institution, but the City and Guilds College did not become a 'constituent college' until 1910, when there was established for its administration a Delegacy responsible dually to the Imperial College and to the City and Guilds of London Institute. The Imperial College as a whole was recognized as a 'School' of the University of London.

The period since then has been one of steady progress. New buildings have been erected in South Kensington for a Students' Union (1910); for the Royal School of Mines and as the Goldsmiths' Extension of the City and Guilds College (1913); for chemical technology, including chemical engineering (1914); for biochemistry and plant pathology (1923); and as students' hostels (1926, 1931). In addition to accommodation in Exhibition Road, Imperial Institute Road, and Prince Consort Road, South Kensington, the College also has a Biological Field Station at Slough, and a mine—the Tywarnhale Mine, near Truro, Cornwall—where instruction in mine surveying is given. New fields of study and research have been opened up, and the principal departments in the College are now as follows: Botany, with Biochemistry; Zoology and Applied Entomology; Chemistry; Physics, including Technical Optics; Meteorology; Geology, with Mining Geology and Oil Technology; Metallurgy; Mining, including Mining Engineering; Mathematics and Mechanics; Civil Engineering and Surveying, including Hydraulics, Highway Engineering, and Concrete Technology; Mechanical Engineering and Motive Power; Electrical Engineering—Power and Telecommunications; Chemical Engineering and Applied Chemistry; Aeronautics.

In the evolution of the Imperial College the diverse visions of the Prince Consort, of de la Beche, of Huxley, and of the City Fathers—the founders of its component institutions—have all been realized in ample measure, though perhaps not always in the manner first intended. Looking back over the past century, one cannot help being impressed by the extent to which the original institutions developed on lines that enabled them later to be fused into a homogeneous whole; little had to be discarded at any stage. The fundamental aims of the component bodies had always been similar, although changing circumstances brought variations from time to time in their short-term policies. Thus, at one time the training of science teachers was recognized as a most urgent requirement, as was emphasized in the formation of the Normal School of Science. But since the federation, under the guidance of successive Rectors—T. W. Bovey, Sir Alfred Keogh, Sir Thomas Holland, Sir Henry Tizard, and now R. V. Southwell—the predominant objective has been the provision of trained scientists and technologists for direct service to industry and agriculture in this country and overseas.

A strong bias towards experimental work conducted by students themselves has long characterized undergraduate courses in the College. Contacts with industry have been close, and the building up of vigorous schools of research in most departments of the College has greatly enhanced its prestige throughout the world. Before the recent war increasing numbers of post-graduate students were coming from overseas, especially from the Dominions, for advanced study and research, and a resumption of this welcome invasion on a still larger scale may now be expected. New links have already been established with sister institutions overseas by the conclusion of friendly agreements with the Massachusetts Institute of Technology in the U.S.A. and the Indian Institute of Science at Bangalore.

In entering upon a new century of activity it is realized that there is much to be done—and not only as regards teaching and research. For many years numerous students' societies and clubs have flourished in the College, and several, such as the Imperial College Boat Club, have achieved high reputations in their respective fields. But limitations of residential accommodation—always a difficulty in London—have prevented many students from obtaining full benefit from these organizations, which have such an important part to play in the building of character. It has been decided, therefore, that the centenary shall be marked by a resolve to do everything possible to develop a fuller corporate life in the College so that it may the better be enabled to serve the needs of the community in the years to come.

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Coral reefs

T. A. STEPHENSON

In this article, illustrated by his own paintings, Professor Stephenson gives a remarkably vivid account of the appearance of typical coral reefs as seen by one who is both a biologist and a connoisseur of beauty. Such accounts are all too rare in biological literature. They provide a most valuable supplement to the preserved material, photographs, and purely technical papers on which the great majority of biologists have to base much of their work.

The plates illustrating this article are reproductions of oil sketches made on the Great Barrier Reef of Australia during the course of an expedition which carried out a biological and geographical study there in the years 1928–9. The results of the expedition's work have been issued in several volumes by the British Museum (*Great Barrier Reef Expedition*, 1928–9, 'Scientific Reports,' 1930 onwards), but these sketches have not before been published.

Coral reefs are as various in appearance as gardens, fields, or any other landscape features, and on any one reef a great variety of scenery may be visible. Moreover, although coral reefs are rocky structures built up from the skeletons of living organisms (corals, algae, and various invertebrates other than corals), they vary very much in the extent to which they are 'alive.' Apart from reefs which are dead altogether (i.e. which were constructed in earlier times), there may be found reefs on which the living and growing coral is so small in amount as to be inconspicuous, the bulk of the reef consisting of dull grey eroded rock of dreary aspect, offering little to attract the eye but for individual plants and animals inhabiting pools on its surface, among which may be seen, perhaps, a starfish marked by a pattern like that of a Turkey carpet or another the colour of washing-blue. Even on a reef which has round its edges a rich and healthy growth of living coral, it is often possible to walk for miles without seeing any. The tops of such reefs form immense sandy flats, with dingy grey boulders or patches of dead coral rock in varying amounts, and with trailing dull green or even blackish plants growing in or on the sand. There may be innumerable pools, the populations of which sometimes show more varied forms and brighter colours; but to see the coral growth at its best one must look for it at the seaward edge of an actively growing reef, where, from about the level of low water of spring tides downwards, the whole slope will be carpeted with a bewildering array of form and colour which rivals anything to be seen on earth.

As a contrast to the somewhat dingy picture conjured up by half-dead reefs and endless sand-flats, we may describe one of the reefs forming the oceanic edge of the Great Barrier. These 'Outer Barrier' reefs form a line of ribbon-like strips with gaps between them, which separate the Pacific Ocean from the shallower waters of the lagoon between them and the mainland. One of these ribbons, known as Yonge Reef, was visited by several of us in 1929. Here, almost every aspect of the landscape was full of colour and brilliance, and we were in a world utterly unlike anything familiar to us. The sense of unreality was extraordinary. On the one hand was the great line of Pacific breakers crashing down with immense power on the seaward edge of the reef; yet the reef destroyed their force so effectively that it was possible to stand within a few yards of them and to see submerged corals on the slope below them reflected in their curling crests before they broke, and to look down into clefts in the edge of the reef at such corals themselves. That the reef should check the breakers so effectively seemed the more amazing in that it was itself so low, so flat, so apparently powerless; it is a reef which at high water is completely submerged by the sea, and which emerges very little above sea level even at the lowest spring tides. The ability of individual corals to withstand the direct shock of the breakers enhances this impression. That some of them should do so is understandable enough, because they have massive forms which can be detached from the reef only with difficulty, with the help of hammer and cold chisel; but others are so slightly built that the least tap from foot or chisel will shatter them, while they withstand the crash of the breakers uninjured. The highest part, or crest, of this ribbon

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PLATE 2 – *A giant clam* (Tridacna derasa) *in a shallow pool on the reef flat at Low Isles, Queensland. The rounded masses to right and left of the clam are living corals* (Porites); *the branching growth* (top right) *is another species of coral* (Montipora ramosa); *the curled fronds* (top left) *a seaweed* (Padina); *the honeycomb-structure* (bottom left) *another coral* (Goniastrea). *The blue starfish is* Linckia laevigata.

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PLATE 3 – *A growth of living coral on the top of a small coral islet on the landward side of Yonge Reef, Outer Barrier, Queensland. All the coral visible belongs to the genus* Acropora *(the leading reef-builder), but is very variable in form from one species to another. The yellow and violet colonies with thumb-like branches are* A. gemmifera, *the brownish brackets with pale edges* A. hyacinthus, *the irregular cream-coloured shapes* A. palifera.

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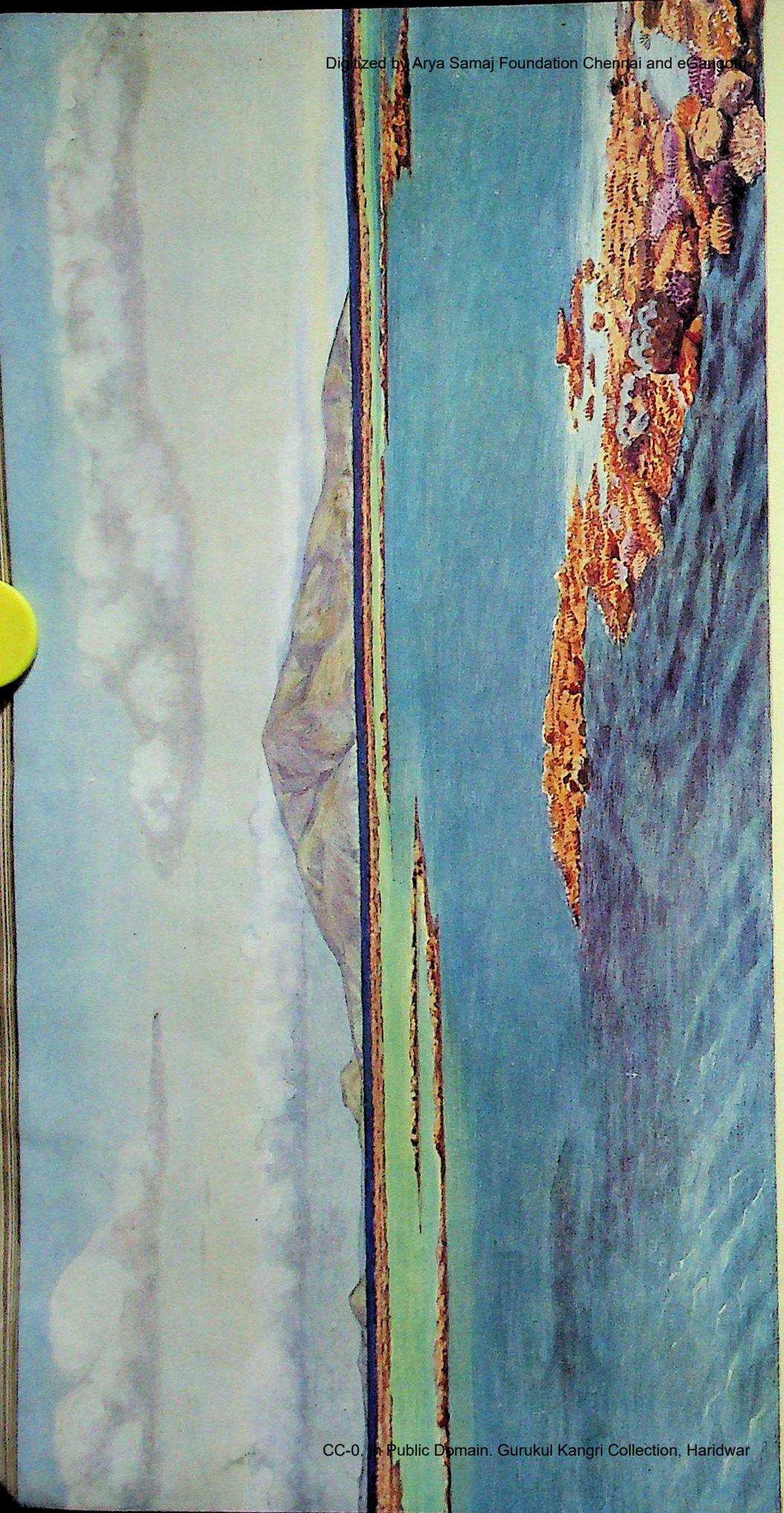

PLATE 8 – *View of part of the landward side of Yonge Reef, Outer Barrier, from the deck of a motor-launch. The mountain is Lizard Island, and beyond it the Queensland mainland is visible. The bright blue and green water is shallow water over white sand, and the dark line below the mountain is the deeper water of the lagoon between barrier and mainland. For further description see the text.*

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of reef has the form of a wide low ridge about 160 yards wide and over three miles long, set back about 100 yards from the breakers. This ridge gives the effect of a broad carriage-drive isolated in the ocean, with the breakers along one side and the brilliantly coloured water to landward of the reef on the other. The colour of the ridge itself is by no means drab; the ground is pink, being covered by a crust of corallinaceous algae, and from this pink background arise corals and other organisms showing a wide range of different colours. The colours in the hollows and on the coral masses between the ridge and the breakers are even more varied and beautiful. A scene of another type is provided on the sheltered side of the reef away from the breakers, and this is illustrated in plate 8, which was sketched from the deck of a motor-launch anchored as near to the main reef as was safe. The reef breaks up, on this side, into a great many separate islets of coral, many of them with precipitous or overhanging sides, arising from a floor of extremely clean white sand or gravel. The tops of these islets just appear above sea level at extreme low water, and some of them are seen in the foreground, covered with living coral. The brightest colour, however, is provided by the water itself. This, varying from a brilliant green in the shallows to a bright blue where it deepens, is far from being exaggerated in the sketch; it has a lambent flame-like quality which cannot be reproduced in paint. The shallow water, against the white paint of the launch, had the quality of a copper flame, the slightly deeper water rather that of a sunlit solution of copper sulphate.

When it is possible to see a coral reef as a whole, from a distance, its appearance varies according to its nature, and two examples may be seen in plate 1. This was sketched from near the top of the 1,100 ft. mountain (Lizard Island) which is seen on the horizon in plate 8. In the foreground, beyond the foothills of the island, are seen irregular coral reefs shown as purplish patches in the shallows. Out to sea are three large reefs (Eagle Island reef, M reef, and L reef) rising from the floor of the lagoon between Outer Barrier and mainland (seen in the distance). Large and solid though these reefs are, they seem, from such a height and distance, to float on the sea like wraiths.

A scene very different from what has already been described is presented if one descends below the surface of the sea, among the growing coral itself, with the assistance of a diving-helmet. Beneath the sea one is in another world at once, cut off completely from that we know. The surface makes an absolute barrier, a roof through which nothing can be seen; the sea in fact has become sky. It is a far more limited sky than ours: it contains infinitely less depth and distance, and is usually of a delicate bluish green, but shading away at the edges as if it were sky. Sunlight filters down through it with a distinctly strange effect. As a rule, the landscape is all foreground with vague shapes behind, and there is no distance. The scene begins with a floor of sand and stones, with corals mounted on some of them. From this floor rise towering rocks, ending above one's head, which sometimes attain the dimensions of cliffs. From the sides and tops of these spring corals of every size and colour. There are delicate branching sprays; rounded forms; antler-like formations; and, above all, spreading vase-shaped or bracket-like structures, some of which reach as much as eight feet across and will support the weight of a human being. The scene is invariably enlivened by the presence of numbers of small fish. Tiny green or yellow ones swim in and out among the branches of a fawn-pink coral, perhaps as many as fifty of them to a single colony. Larger fishes of the most bizarre shapes and colours are present also, in smaller numbers—black and gold, electric blue and gold, striped like a zebra, or showing all the colours of the rainbow at once. These fish usually take no notice at all of a diver, unless he makes a sudden movement in their immediate direction.

It is sometimes supposed that the colours to be seen on coral reefs are universally brilliant. This is a mistake. It is true that in the most highly coloured parts the variety of shades is very great, and this forms part of the attraction. But very often the prevailing tints are yellowish brown or pinkish brown, with a brilliant contrasting note here and there. The beauty, which is very real, depends by no means on brilliance alone, but also on variety of form, and more particularly upon texture. The corals often have a strangely velvety appearance, in strong contrast to their actual hardness. The perfect delicacy of form and colouring, the fineness of grain and texture, and the change of colour which so often occurs at the tips of growing branches (as, for instance, from fawn to vivid hyacinth blue), produce an effect which defies description. Two of the accompanying plates (3 and 4) show the general appearance of coral growths seen at close quarters, but unfortunately one cannot pass on the exquisite texture without spending far more time on the drawing than was available. Plate 3 shows coral

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exposed to the air at the time of low water, on one of the islets to landward of Yonge reef; plate 4 shows a growth on another reef, as seen just below the surface, at low water, from an anchored dinghy.

The actual animals (polyps) which produce the coral are similar to sea anemones, and are carnivorous, however flower-like they may appear. The colours of the living coral reside not so much in the tentacles of the polyps as in their bodies and the tissues which connect them; it is the whole film of flesh covering the skeleton which is coloured. The tentacles of the polyps, however, are not usually seen by anyone visiting the reef in daylight, because most of the polyps expand and feed only or mainly at night. There are exceptions to this, and two of them are illustrated in plates 5 and 7. In plate 5 are seen several unusually large polyps belonging to a species of mushroom-coral (*Fungia*), expanded in daylight among the dead and living coral in a shallow pool. Plate 7 shows a colony belonging to a species of *Turbinaria*, a wavy dish-like structure covered on its upper side by expanded polyps. The remaining plates illustrate some of the other animals common on Australian reefs. In plate 2 a giant clam (*Tridacna*) is seen surrounded by living coral and seaweed; plate 6 depicts a giant sea anemone (*Stoichactis*), its Prussian-blue tentacles making a curious contrast to its dull background of dead coral with pinkish algal encrustations.

Mention has already been made of small green and yellow fish which swim in and out among the branches of some of the corals. These fish illustrate an occurrence which is very commonly seen on coral reefs—the close association of animals of quite different kinds which is known as 'commensalism.' Thus, in the case already mentioned, each coral colony possesses its own exclusive shoal of fish, which apparently never venture far from the shelter of the branches. Other corals are often accompanied by crabs or prawns. There is, for example, a very common yellowish-brown branching coral (*Pocillopora bulbosa*) living in shallow pools on the tops of reefs, which frequently shelters a beautifully coloured red and purple crab (*Trapezia cymodoce*) about an inch across; and the same coral less often harbours small crabs of other species, or prawns. Prawns, in fact, are among the commonest commensal animals, and brightly coloured species of the genus *Periclimenes* often make their headquarters not only with corals but also with sea anemones, which themselves may shelter not only prawns but fish. The anemone represented in plate 6 (*Stoichactis kenti*) is unusual in several ways. In the first place it is very large for an anemone (up to eighteen inches or more in diameter), secondly it is often bright blue, which is not a common colour in anemones. Thirdly, it often shelters small commensal prawns (*Periclimenes*) and fish (*Amphiprion* and *Actinicola*) which are strikingly unlike it in colour. The whole question of the coloration of commensals is one which would repay further study. While many of them tone in with the coral they inhabit, so that they form a part of its own colour scheme, others contrast with it quite sharply and yet produce no inharmonious effect, as when brilliant golden-yellow fish live with a pinkish brown coral. On the other hand, some of them—and this applies to crabs, prawns, and fish—adopt a very peculiar colour scheme which is quite out of harmony with the background colour of the anemone or coral, and reminds one forcibly of a vividly striped football jersey. These species exhibit variations on one combination of colours—black, scarlet, and bright opaque cream, arranged in stripes and making them very conspicuous. This particular coloration is found in the fish and prawns mentioned in connection with *Stoichactis*, and again in some prawns which we saw one day when diving in about five fathoms of water. On this occasion a coral about two feet across had its polyps expanded so that the whole colony was covered by a carpet of dull brown knobbed tentacles; and among the tentacles were about two dozen of these striped prawns of various sizes, all exhibiting the curious swaying motion, as if combing the tentacles, which is characteristic of them, giving the extraordinary effect of a brightly coloured submarine ballet. The striped colour scheme is seen again in a small crab of unique habits, which we did not see on the Australian reefs although we found it under dead fragments of coral on some of the reefs round the island of Mauritius at a later date. This is the well-known (but rarely seen) *Melia tessellata*, and its peculiarity lies in the fact that it habitually carries two small sea anemones about with it, one in each nipper, and when in danger holds them up as if they were boxing-gloves. Naturally the relationships between very different species, of which these are examples, have provided opportunities for studies in animal behaviour of certain types—to what extent the associations are of mutual benefit to the partners, to what extent one exploits the other, and so forth. While there has been a certain amount of recent experimental work which partly answers such questions, there is scope for a great deal more.

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The present position of theoretical physics

N. F. MOTT

Investigation of atomic phenomena showed that Newtonian mechanics are not of universal truth. Recognition of this fact was followed by the development of a new system of equations known as quantum mechanics, of which Newtonian mechanics proved to be a special expression valid for relatively large particles. Professor Mott discusses the influence of the theory of quantum mechanics on recent developments in physics, and describes certain phenomena for which even the new mechanics may not provide an explanation.

The interval between the two wars was a period of sensational advance in atomic physics. It saw the first splitting of the atom achieved by man; it saw also the discovery of several new particles, the positive electron, the meson, and above all the neutron, which pointed the way to the atomic bomb; but perhaps in the history of science it will be remembered foremost for the discovery of the system of equations which is known alternatively as quantum mechanics, wave mechanics, or matrix mechanics. Less than a year after the explosion of the first atomic bomb, with its profound effect on the war and on the ensuing peace, it may seem strange to ascribe such importance to a system of equations, especially as, in view of the several different forms in which the theory was introduced and the controversies between scientists and philosophers which attended its birth, it is not generally realized, except by professional physicists, how remarkably successful it has been; but it now appears that we have in quantum mechanics a body of knowledge which in its proper field is likely to last just as long as Newton's laws of motion will last in theirs—which means for just as long as scientists and engineers have a place in civilized communities.

Newton's laws of motion were so successful that until the present century most people believed that they were true for all the phenomena which make up the science of physics. We now know, thanks to the work of Einstein, that Newton's laws break down for particles moving very fast, with speeds comparable with that of light, and that Newtonian mechanics must be considered as a special case of the more general relativistic mechanics, valid only for particles moving with comparatively low speeds. We know also that Newton's laws are not true at all for the very small and light particles (electrons, protons, neutrons) of which atoms and molecules are built up. To explain the behaviour of these particles, quantum mechanics have been developed, and the Newtonian system must be considered again as a special form of quantum mechanics valid for heavy particles like cricket balls, projectiles, or planets. But none the less, in their proper field Newtonian mechanics remain completely satisfactory. No one would dream, for example, of using either quantum mechanics or relativity in ballistics to calculate trajectories of bombs, shells, or rockets; the corrections introduced if this were done would be utterly beyond the possibility of measurement, and so in this field Newtonian mechanics remain true. The same can be said about much of astronomy, especially the calculation of the motion of the earth and the planets round the sun; the Nautical Almanac Office does not need the principle of relativity to predict the date of a forthcoming eclipse.

Quantum mechanics, like Newtonian mechanics, are not the ultimate theory of inanimate nature; but, like Newtonian mechanics, for a very wide class of phenomena they give for all practical purposes the right answer. This class is so wide that until the present century it would have been thought to comprise the whole of physical knowledge. It includes, to begin with, the whole of chemistry, the science that deals with the forces which enable atoms to combine together to form molecules and solids. It accounts with sufficient accuracy for the behaviour of electron beams and thus for electronics generally, and also for nearly all spectroscopy and for the production and properties of X-rays. It is only in those new and, until the atomic bomb, rather remote subjects, nuclear physics, stellar energy, and cosmic rays, that phenomena occur which may not be within the competence of quantum mechanics to explain.

The work of Rutherford and Bohr in the early years of this century established the nuclear model of the atom on a firm footing. The well-known and important features of this model are the

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existence of the heavy positively-charged nucleus in the centre of the atom and of electrons which move round it. The only properties of the nucleus that matter for chemistry and for all allied sciences are its mass, which determines the atomic weight of the atom, and the charge, which determines the number of extra-nuclear electrons (the atomic number). On this number depend the position of an element in the periodic table, all its chemical properties, and, except for a few finer details, its optical and X-ray spectra. The complicated internal structure of the nucleus can be revealed only by the special techniques of the high-voltage laboratory or the atomic bomb, and, except for the phenomenon of natural radioactivity, it was quite without influence, as far as we know, on the properties of animate and inanimate matter on this planet until scientists began to investigate it. On the cosmic scale, nuclear phenomena are of course of primary importance, being responsible for the heat and light from the sun and stars; but it is remarkable how little indication the nucleus gives of its inner structure in the behaviour of material things on the earth outside of physical laboratories.

The theory known as quantum mechanics or wave mechanics seems quite sufficient to account for the behaviour of the extra-nuclear electrons. An entirely satisfactory relativistic branch of the theory does not yet exist, though here, too, great progress has been made. Since, however, in atoms and molecules the velocities of the particles are small compared to that of light, this does not matter so far as the applications of the theory to chemistry and to allied subjects are concerned. In this field the findings of the theory seem to be always in agreement with experiment. Calculations based on the theory have been made of the energy levels of various atoms, of the binding energy of some of the simpler molecules and chemical bonds, and of the scattering of beams of electrons by gaseous molecules. The differential equations that have to be solved are complicated, and much numerical work is needed to obtain a fairly exact solution, but when this is done the agreement with experiment is very satisfactory.

During the few years after the discovery of quantum mechanics the theory was rapidly applied to all the simple problems of atomic physics, with uniform success. Thus Heisenberg and Hylleraas gave a treatment of the spectrum of helium, Sommerfeld and Bloch explained the outstanding facts about conduction in metals, and London and Heitler gave the first complete theory of the homopolar bond. It was a golden age for the young research worker, who could perhaps master the ideas of the new mechanics more easily than his seniors, and could then use them to explain phenomena unexplained for a hundred years. That period has now passed. The centre of interest in non-relativistic quantum mechanics has now passed to complicated problems which derive their interest from physical or organic chemistry, metallurgy, or industrial physics. In these fields advances will be made by experimentalists with a good knowledge of quantum mechanics, or by theorists with a very wide knowledge of physics and chemistry; there is little scope there for the research worker whose interest in the subject is mainly mathematical. A particularly promising subject seems to be the study, both theoretical and experimental, of the flaws that exist in solids and their effects on the strength of the solids. In a subject such as this, neither theory nor experiment can make much progress without the other.

In the field of knowledge where quantum mechanics ought to be valid, the outstanding unsolved problem is the phenomenon of superconductivity, or the disappearance of the resistance of certain metals at low temperatures. It is probably true that nearly every eminent theoretical physicist has, at some time or other, tried to explain this property, but without success. The problem of the motion of a large number of interacting electrons in a metal is of course extremely complicated; it is not possible to obtain a solution of the equation of motion without introducing drastic simplifications. When this is done, the equations do not predict that anything like superconductivity should occur, and no one has yet been able to tell whether the exact solutions would do so.

We turn now to the field of nuclear physics and cosmic rays, of stellar interiors and very high energy particles. It is in this field that something totally new is to be found out: it is not a question, for the theorist, of applying known laws to complicated phenomena, because in this field the known laws do not always work, and modifications of a fundamental nature will have to be introduced. The difficulties are twofold—the contradictions in the theory that arise for particles moving with velocities near to that of light (represented by c), and our lack of knowledge of the laws of force between nuclear particles.

The attempt to build up a relativistic form of quantum mechanics has had a most interesting history. The first big step forward was made by Dirac, who showed in 1928 that a relativistic generalization of Schrödinger's original wave

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equation could be given if—and only if—the electron was assumed to have a fourth degree of freedom, the so-called 'spin' that spectroscopic evidence had already shown to exist. Dirac's equation was brilliantly successful in explaining the spin itself and in giving a quantitative account of many phenomena in which the spin is involved. Unfortunately, however, it predicted the existence of 'states of negative energy'; according to the theory of relativity, the energy W of a particle of mass m moving with velocity v should be given by the formula:

$$W = mc^2/\sqrt{(1 - v^2/c^2)}$$

and Dirac's equation predicted that both the positive and negative values of the square root should be admissible. Nothing in nature corresponding to an electron with negative energy was known to exist, and Dirac tentatively suggested that the states of negative energy should be 'filled up' by a continuum of electrons, in general not making their presence felt except by keeping other electrons out. This rather strained hypothesis had an astonishing confirmation in the discovery of the positive electron, which finds a ready explanation as a 'hole' where an electron is missing from the continuum. Nevertheless the whole conception leads to many difficulties, especially in the theory of the interaction between radiation and charged particles moving with very high velocity, such as occur in cosmic rays.

The difficulties which occur in nuclear physics are of a somewhat different nature. The whole successful theory of quantum mechanics for the extra-nuclear electrons is based on the assumption that electrons and protons attract each other, and electrons repel each other, according to the law of the inverse square. The nucleus, however, is not built up of electrons and protons, but, according to the most recent theories, of protons and neutrons. The number of protons is thus equal to the atomic number, and the number of neutrons to whatever is necessary to make up the atomic weight. Nothing is known *a priori* about the nature or magnitude of the interaction between protons and neutrons, and thus it is hardly possible to say at present whether quantum mechanics in their present form are applicable to the nucleus or not. Certainly some of their more qualitative features are valid, in particular the existence of quantized energy levels; but it is as yet uncertain whether they would be adequate, once the interaction forces were known, to calculate for example the energy with which two protons and two neutrons combine together to form an α-particle.

At present one of the most interesting and promising lines of investigation is the attempt being made to connect the interaction between proton and neutron with the existence of the new charged particle, the meson, of mass intermediate between the proton and electron, which has been shown to exist in the cosmic rays. A number of meson theories of the interaction exist, but none of them is in entire agreement with experiment. Whether ultimate success will be obtained along these lines, or whether a radically new approach is necessary, only time will show.

An article on the present position of theoretical physics would be incomplete without some mention of the philosophical implications of the subject, although this article gives little space for so large a topic, and any remarks must be coloured by the prejudices of the writer. However, it has to be faced, in his opinion, that the notorious 'uncertainty principle' of Heisenberg has come into science to stay. The hypothesis that it is impossible simultaneously to measure the position and velocity of a particle is deeply embedded in the structure of the quantum theory, and any attempt to remove it would bring the whole theory to the ground. It is not brought forward because of some temporary limitation in the accuracy of our measuring instruments which future experimental work may remove, but much more as a direct deduction from certain experimental facts (electron diffraction), which without the uncertainty principle cannot be explained in any rational way. The tendency at the moment in modern developments, especially those of the Copenhagen School, is to extend the scope of the principle rather than to limit it.

It seems therefore highly improbable that physics will ever revert to the position in which it could be believed that the future was inherent in the present, in the sense that a sufficiently well-equipped computing service would be in a position to calculate the future, if given all the facts about the motion of all the particles in the universe at the present time. The equations of mathematical physics appear to preclude any such ambitious project, whatever the resources that the imagination can assign to it. The contribution to philosophy of recent discoveries is therefore rather negative; certain statements about the mechanistic nature of the universe that were made in the last century may have to be withdrawn, or at any rate cannot command the authoritative support of science. Positive conclusions can also be drawn but are outside the present scope.

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Moulds and tropical warfare

G. SMITH

Even in temperate zones the damage to property resulting from the activities of biological agents, of which moulds are among the most destructive, is of considerable economic importance. In the tropics, where ideal conditions for the growth of moulds are of common occurrence, the destruction can be very serious indeed. This fact was very forcibly demonstrated during the recent war; the methods then devised for the protection of military equipment can in many instances be profitably applied in domestic and industrial fields.

The war with Japan created numerous problems for our armies and those of our Allies. Many of them, in particular the appalling difficulties of jungle fighting and the severe strain on human endurance, have been given some publicity, but less has been heard of a campaign against the enemies which attacked equipment and thus very considerably reduced the efficiency of the fighting forces.

During the early part of the Far Eastern war, losses of food, clothing, shelter, tools, arms, ammunition, and especially of the many precision instruments used by a modern army, were on an alarming scale. Much of the damage could be traced to faulty methods of packing, methods which made insufficient allowance for the inevitable rough usage to which stores were exposed in very difficult country. There remained of the total loss, however, a high percentage which was due to the activities of biological agents, and the principal offenders were moulds.

Damage due to micro-fungi is a serious matter even in this country, but under jungle conditions it is many times worse. Growth of moulds is always associated with a humid atmosphere, and the higher the relative humidity the more rapid is growth and the more varied is the micro-flora. In the jungles of Burma and the Pacific Islands, where most of the fighting occurred, the relative humidity may lie between 90 and 100 per cent. for considerable periods, with little variation between night and day. Under these conditions, mould growth on susceptible materials is extremely rapid, and it is not easy to design equipment which will give satisfactory service over a reasonable period.

Early in 1943 the Ministry of Supply initiated a programme of research on methods of tropic proofing. A number of advisory committees were formed, composed of representatives of the Services and of a number of scientific institutions. A test chamber was fitted up at the London School of Hygiene and Tropical Medicine, in which atmospheric conditions were maintained to imitate as closely as possible those obtaining in tropical jungle. After study of meteorological data for various stations within the war zone, it was decided to maintain a day temperature of 85° F (30° C), with a relative humidity between 98 and 100 per cent. and very slow circulation of the air. The temperature was allowed to fall naturally at night, resulting in supersaturation and then condensation, very much as happens during the night in the jungle. In the beginning, the chamber was thoroughly inoculated with a number of species of moulds which were known to grow on stores in the tropics, and, for a time, all materials put in the chamber for test were similarly inoculated. Soon, however, it was found that a micro-fauna, chiefly psocids and mites, had colonized the chamber, being attracted by the warm, humid conditions, and inoculation became unnecessary, since these creatures distribute mould spores quite efficiently. For the testing of hundreds of small samples it was found more convenient to incubate in glass vessels containing water to maintain a saturated atmosphere. These were incubated in a constant-temperature room at 30° C, and test samples were always inoculated.

For some time the original equipment was adequate to deal with the programme of research, but eventually the demands of all three Services increased to such an extent that the work had to be shared between a number of establishments, and several other tropic chambers were put in commission. Nor was work on the mould problem confined to Britain, for at an early stage parallel investigations were undertaken in Australia and the U.S.A. In order to prevent undue overlapping there was close collaboration from the very beginning, with free interchange of reports between the three countries.

It would be impossible to give here an adequate

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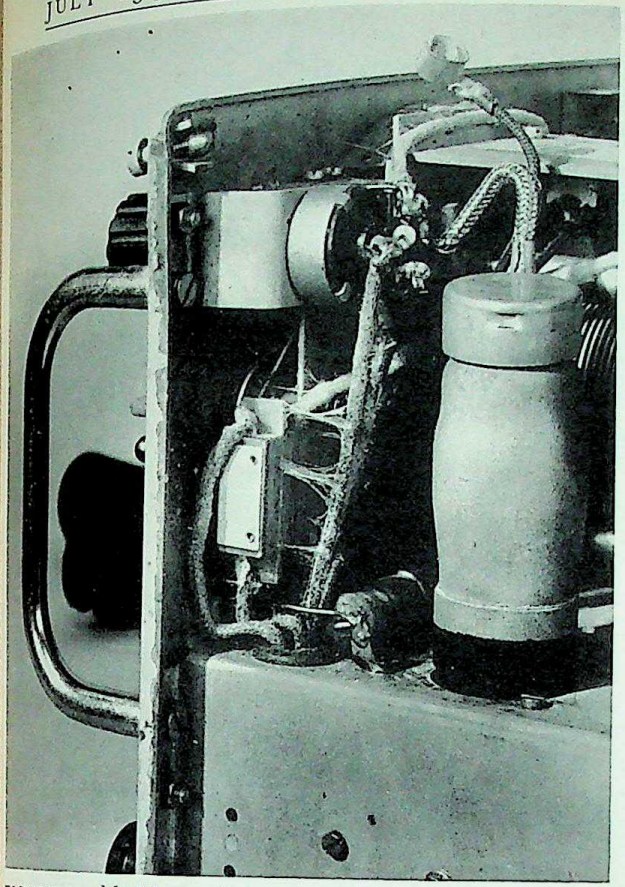

FIGURE 1 – *Mould growth in a wireless set. Hyphae bridging some of the components.* (*By courtesy of the Ministry of Supply.*)

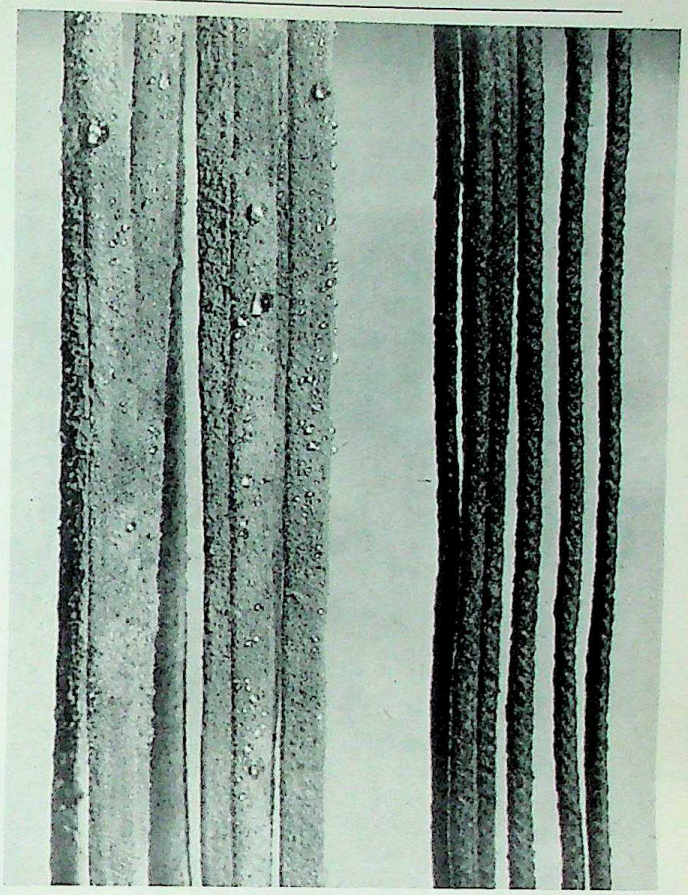

FIGURE 2 – *Fabric bootlaces after incubation in a 'tropic chamber.' (Left): Unproofed. (Right): Chrome-proofed.*

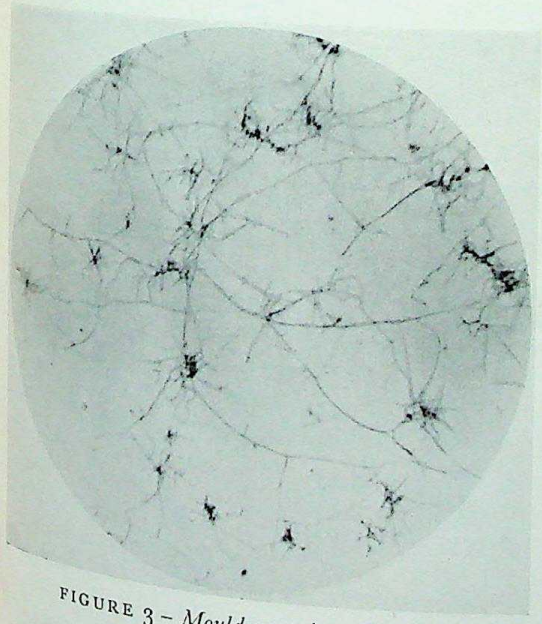

FIGURE 3 – *Mould on prism.* (× 25.)

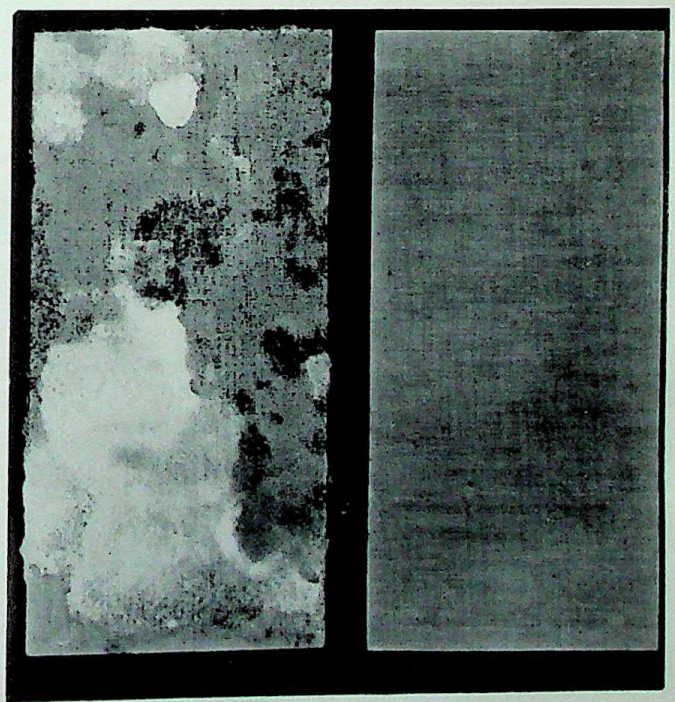

FIGURE 4 – *Fabric-filled bakelite. (Left): Unscoured fabric. (Right): Scoured fabric.*

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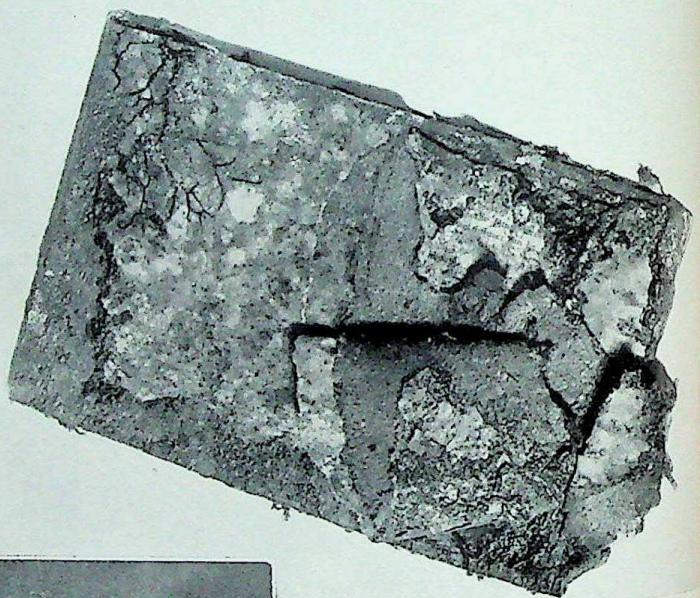
FIGURE 5 – *Binocular, fitted with capsules containing silica gel, after two months under tropical conditions. Outside corroded and slightly mouldy. Inside in good condition.*

FIGURE 6 – *Instruction booklet almost completely disintegrated by moulds and moisture.*



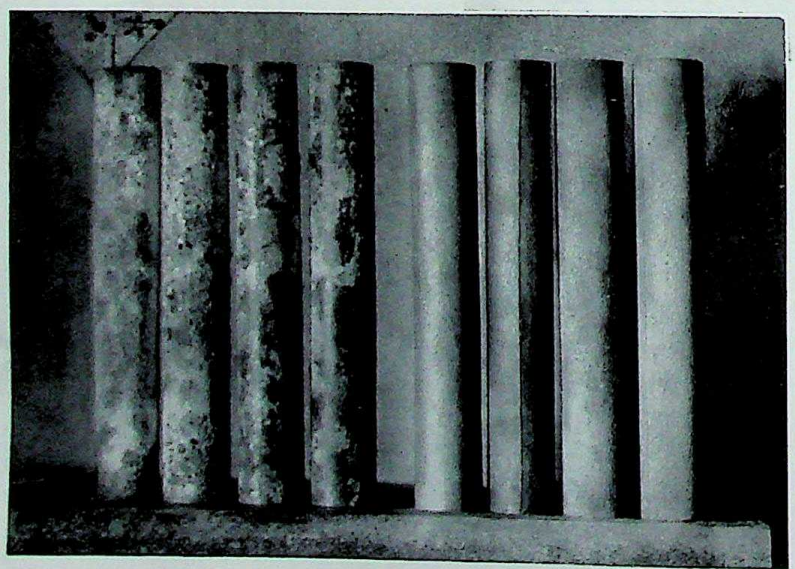


FIGURE 7 – *Rolled paper ammunition tubes. (Left): Casein glue. (Right): Urea-formaldehyde glue.*

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account of all the lines of investigation which have been followed. Only a few, therefore, of the more important methods of mould-proofing will be described.

ELECTRICAL EQUIPMENT

The first urgent problem to be attacked concerned the occurrence of mould in wireless sets and similar apparatus. Figure 1 shows part of the inside of a service wireless set attacked by mould, hyphal strands bridging various components being clearly visible. This kind of damage occurs mostly in store before sets are issued, since, when a set is in use, considerable heat is generated, sufficient to dry out the set and to kill most moulds, and, if there are no long idle periods, any mould growth which occurs will never reach the stage shown in the photograph. There is seldom any direct destruction of insulating materials, even when mould growth is extensive, the danger being from leakage between high-tension circuits along the moisture-laden hyphae.

The provision of mould-proof wireless sets is no easy matter, but much progress towards a solution of the problem has been made by building sets entirely from materials which will not provide food for moulds. The more important of the alterations which have been made have been the substitution of plastics (chiefly polyvinyl chloride, 'P.V.C.') for fabric insulation on conductors, the careful selection of waxes and other impregnating compounds, the complete elimination of cork packing and insulation, the use of paints containing fungicides, and the restriction of the use of laminated plastics to those containing inert or suitably protected fillers. However, re-design is only a partial solution, and, in order to provide protection for sets already manufactured and issued, methods of spraying or painting with lacquers containing fungicide have been developed. These lacquers are not easy to apply, since a good deal of preliminary masking of metallic contacts has to be done, and the final result is not a permanent protection. Nevertheless, if lacquering is carried out intelligently, it certainly serves to cut down replacements very considerably.

FABRICS

Fabrics of various kinds form parts of so many items of equipment that they have naturally received much attention. Fortunately a large amount of research had been carried out before the war by the research associations, in particular the British Cotton Industry Research Association, and the solution of wartime problems was often a question of adapting existing knowledge rather than seeking new methods of proofing. 'Shirlan' (salicylanilide) has been used extensively in clothing and bedding, that is in fabrics which require protection during transport and storage but which, after issue, are either frequently laundered or worn to destruction. However, in view of the many demands for 'Shirlan' during the war, the supply position soon became serious and substitutes had to be sought. In preliminary tests a number of compounds used as accelerators in rubber manufacture showed considerable promise, and one of these, mercaptobenzthiazole, proved to be quite as effective as 'Shirlan.'

Valuable as these antiseptics are, they cannot be used for any fabrics which are normally exposed to the weather, as they are fairly rapidly leached out. For webbing, waterproof canvas covers, and tent material, chromic oxide is as good as anything found up to the present (see figure 2). For some fabrics it is used alone, at the rate of approximately 1 per cent. of the weight of the material, but it is more usually mixed with ferric oxide to form what is known as 'mineral khaki.' For heavier waterproof sheetings, such as tarpaulins, and for ropes, copper naphthenate has been widely used.

For all fabrics composed of cellulose a very simple method of enormously increasing resistance to moulds is to scour by boiling for at least an hour with a 1 per cent. solution of soda ash. Very few organisms can attack pure cellulose, and the liability of fabrics to become mouldy is due to the presence of small amounts of more readily available food material, either in the size used for weaving or in the natural non-cellulosic constituents of the raw fibres. Many moulds do not attack cellulose at all and grow entirely at the expense of these impurities, while even those which can rapidly destroy cellulose do so only if supplied, in addition, with certain metallic salts. Figure 4 shows the remarkable efficiency of scouring. It is a photograph of two sheets of fabric-loaded bakelite, one made with loom-state fabric, the other with scoured fabric, after incubation for four weeks in a tropical atmosphere.

PAPER

In supplying an army, paper is used in very large quantities, for stationery, instruction books, packing, labelling, and as built-up containers for ammunition. Most common varieties of paper, when exposed to a humid atmosphere, lose most of their strength from the effects of moisture alone

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before damage due to moulds is appreciable. Nevertheless it is often possible to dry out paper which is merely wet, but, if mould attack also is extensive, the damage is irreparable. Figure 6 shows an instruction book reduced to a mass of pulp by the combined effects of moulds and moisture.

A considerable amount of research during the war was therefore directed to the production of papers which would retain their strength when wet and to methods of mould-proofing them. Labels have been satisfactorily proofed by treatment with aqueous solutions of sodium pentachlorphenate, while wrapping papers have been treated with copper by the cuprammonium process or in the form of copper naphthenate. In the case of built-up containers the weak point is often the adhesive, but great improvements have been effected by using modern 'plastic' adhesives, such as urea-formaldehyde polymers, instead of the older types (figure 7).

LEATHER

The susceptibility of leather to attack by moulds depends chiefly on the method of tanning. Vegetable-tanned leather, as most people know only too well, rapidly becomes covered with mould under conditions of temperature and humidity far less severe than those obtaining in the tropics. Chrome-tanned leather, on the other hand, has been proved to be almost completely resistant, a fact which links up with the protective action of chromic oxide on fabrics. Semi-chrome leather, as would be expected, is intermediate in resistance. Unfortunately, chrome-tanned leather has physical properties which render it unsuitable for some purposes—boot soles, for example—and in any case the production possible during the war was insufficient to allow of more than a part of the leather equipment being made from this material.

Little is known at present about the effect of mould on leather, a problem now being investigated by the British Leather Manufacturers' Research Association. Certainly luxuriant growth can be cleaned off and the leather appears to be none the worse as regards strength and suppleness. Nevertheless, mouldy articles are unpleasant to handle and, particularly in the case of items of clothing, have to be cleaned frequently. With much equipment the damage is thus to be assessed in terms of the man-hours required for maintenance in good condition. Mould on instrument cases, particularly those for protecting optical equipment, can be more serious, as it may spread to the contents and, in addition, attracts mites. The majority of mechanical failures in leather equipment can be traced either to rotting of the leather owing to contact with iron or to breakdown of the stitching owing to attack by moulds. It is essential that all thread used in making up leather goods should be adequately mould-proofed, preferably by impregnation with chromic oxide.

A large number of experiments have been carried out to test the efficacy of various substances as protectives for vegetable-tanned leather, and to find the most suitable means of application of the selected antiseptics. Oil-soluble organic mercurials, which in other connections have proved to be the most potent of all anti-fungal agents, were first tested, but gave erratic and, on the whole, disappointing results. Undoubtedly the best of all the substances tested is *p*-nitrophenol, a very high degree of resistance being conferred by the addition of 0·3 per cent. of this compound (calculated on the weight of the leather). The antiseptic may be incorporated during manufacture of the leather, but in many cases it is preferably applied to the made-up articles in order to ensure protection of cut edges. It is used as a 1 per cent. solution in methylated spirit or a 50/50 mixture of spirit and water, and is sprayed or brushed on so as to add the correct amount. A somewhat less effective method of application is to treat the articles with dubbin containing 1 per cent. of the antiseptic. Often, of course, this was the only practicable method of treating equipment which was already in commission before treatment by manufacturers became general. Another antiseptic, recommended for use when supplies of *p*-nitrophenol are unavailable, is β-naphthol. It is applied in the same way as *p*-nitrophenol, but is of lower efficiency.

OPTICAL EQUIPMENT

The most interesting, and perhaps the most difficult, of all the problems investigated concerned the occurrence of mould in optical instruments. The problem is a very old one, and a certain amount of rather spasmodic research was carried out before the war, but in peacetime the servicing of damaged instruments is comparatively easy, and the total number in use is only a fraction of those needed in war.

Glass apparently contains nothing on which moulds can feed, certainly neither of the essential elements carbon and nitrogen, yet optical instruments such as binoculars, telescopes, microscopes, range-finders, and gunsights often become unusable after a few months in the tropics. Undoubtedly mould most frequently originates on

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organic matter, dead or alive, which finds its way into imperfectly sealed instruments. The live culprits are mites, which abound in tropical forests, and they gain entry by eating their way through lutings or by creeping along badly fitting screw threads. They carry fungus spores on their hairy bodies, and as they often die in their hiding-place from lack of food, they serve as a source of nutriment for the moulds. In many cases, however, mould growth occurs on glass surfaces on which neither dust nor mites can be detected. The amount of growth is then comparatively slight, usually consisting of a network of fine filaments without any sporing structures. It is nevertheless sufficient to spoil definition, or, if it occurs on a graticule, to interfere seriously with the field of view. Figure 3 shows a fairly typical case of mould on a clean glass prism, the dark spots being knots of mycelium and not dust particles.

Often the growth is entirely superficial and can readily be cleaned off, but sometimes the glass is definitely etched, and has to be resurfaced to restore normal transmission. Even when no etching occurs, stripping, cleaning, and reassembly are jobs for the expert and cannot easily be carried out without a proper workshop.

Instruments of the fixed-focus type are comparatively easy to protect. If accurately made and assembled in a dry atmosphere they cannot develop mould unless the sealing breaks down. On the other hand, all instruments of the focusing type breathe to a certain extent, owing to the pumping action of the focusing adjustment, moist air being drawn in and gradually raising the relative humidity of the contained air to that of the atmosphere outside. It is extremely difficult to ensure that no mould spores enter an instrument during manufacture, and if any are present they will germinate as soon as the relative humidity reaches the critical point (about 75 per cent. for the species most commonly found). In addition, lutings used to seal lenses in cells and cover plates on the bodies of instruments are liable to dry out and crack in dry weather, and then, when humid conditions return, admit not only moisture but mould spores as well. It is probable that the only entirely satisfactory solution of the problem will result from complete redesign of most items of optical equipment, so as to ensure complete sealing even when focusing has to be allowed for. During the war, however, it was necessary to find means of prolonging the useful life of thousands of instruments in use and in process of manufacture.

The first essential was to ensure that all parts of instruments other than the actual optical systems were rendered mould-proof. Lutings, greases, paints, and lacquers were reformulated so that they should contain no ingredients capable of providing nutriment for moulds; this involved testing very many samples in the efforts to combine immunity with all the desired physical properties. Finally, a large number of experiments were carried out in order to find the best means of protecting the glass.

One method which has been extensively investigated is the fitting of instruments with small capsules containing a volatile antiseptic. The capsules, made to screw in from the outside to permit of easy replacement, are provided with diaphragms of sintered glass, through which the vapour can diffuse without any danger of solid particles being dislodged. The method, though attractive in theory, is limited in practice by the difficulty of finding the ideal antiseptic. It must be volatile but not too readily volatile. The vapour must have no action on any of the metals used in the construction of optical instruments, nor must it affect optical cements or lutings. So far, the most promising materials found are *m*-cresol acetate (first used in America and called 'cresatin') and thymol, but neither is entirely free from disadvantages.

Another means of protection which has been tested is the insertion into instruments of capsules containing silica gel, designed to keep the relative humidity of the enclosed air below the point at which moulds can grow. Trials carried out in this country have shown that very small quantities of the desiccant, such as can readily be inserted without interfering with the transmission of light, are effective for several months, even when sealing is far from perfect (figure 5).

There have not been, as yet, sufficient field trials to determine which of the two methods will give the better protection under service conditions, although there is reason to believe that, with improvements in the technique of sealing instruments, it will be possible to give reasonably lasting protection by means of desiccants. They have one great advantage over volatile antiseptics in that they also eliminate trouble due to fogging of lenses by condensed water, but it is possible that a combination of both methods will be found to be better than either alone. In any event a really satisfactory solution of the problem is in sight. This programme of research, like many others designed to solve wartime problems, has led to the development of new methods of lasting value in peace.

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Whales and whaling

L. HARRISON MATTHEWS

By their size alone whales have always arrested the attention of even the most indifferent, and by their peculiar structure and almost unknown ways of life they have long interested the zoologist. Their economic value, too, has not been overlooked by the world of commerce, and the excitement and danger of hunting them have appealed to the adventurous. On this fascinating subject Dr Matthews writes with the authority of one who has himself voyaged to the Antarctic and studied the life-histories and habits of whales at first hand.

Whales form a group apart from all the other mammals—for mammals they are, breathing air with lungs, having warm blood, bringing forth living young, and suckling them on milk. Their remote ancestors more than fifty million years ago were four-footed beasts living on the land, but the process of evolution throughout that immense period of time has left them with a fish-like form, fin-like fore limbs or paddles, and no external hind limbs—though rudiments of these are still to be found embedded in the tissues within the body. The tail is expanded into wide flukes, much like a fish's tail, except that it is horizontal and not vertical; it forms the chief means of propulsion. Some whales, too, have a fin on the back, resembling a fast motor-boat's skeg-keel, which helps in steering a straight course. In harmony with the aquatic habitat, the skin of whales is without the hairy covering usually found on mammals, except for a few scattered hairs on snout and chin (remains of the whiskers and beard) which show their affinities with their fully clothed relations. In compensation for the loss of hair, whales have underneath the skin a thick layer of blubber, a fatty tissue which serves to insulate the warm body from the cold water in which it floats. The aquatic habitat, too, has allowed the development of the great size of some whales. No animal of such size, whose body was not supported by floating in water, could exist; in fact, if a large uninjured whale becomes stranded and left by the tide, it is suffocated by its own weight, which crushes its chest and prevents it from breathing. But not all whales are of gigantic size, for the porpoises and dolphins, which are comparatively small, belong to the same tribe.

There are many different kinds of whales, but they fall naturally into two main groups, the toothed whales and the whalebone whales, the differences between which are closely connected with their food. The toothed whales, as their name implies, are provided with teeth for seizing their prey, which consists of fish and, probably even more important, cephalopods—squids and cuttles. The teeth, unlike those of most mammals, are all similar, being pointed and peg-like and not divided up into incisors, canines, and molars. In many whales, also, they are very much more numerous than in any other mammals, but in some there is a reduction in number; the great Sperm Whale, for instance, has teeth in the lower jaw only, and when the mouth is closed they fit into corresponding sockets in the gum of the upper jaw. In some of the smaller whales the teeth are reduced still further to a single pair, placed near the tip of the lower jaw.

The feeding mechanism of the whalebone whales is quite different. They do not catch individual animals for food, but filter the sea water to extract in bulk the vast numbers of small creatures which are collectively termed 'plankton.' Plankton consists of all the small plants and animals, many of microscopic size, which float in enormous numbers in the upper layers of the sea; their great abundance is shown by the fact that the largest whales feed on little else. The apparatus of the whalebone whales for filtering plankton out of the sea is peculiar. There are no teeth in the mouth, but hanging from the upper jaw is a series of many fibrous horny plates set crosswise on each side, where the upper teeth are placed in ordinary mammals. These horny plates are misnamed 'whalebone.' The inner sides of the plates are frayed out into separate fibres, so that a sort of hairy mat, supported by the plates, is formed on each side of the mouth. When the whale is feeding it takes in a mouthful of sea water together with its contained plankton, shuts the mouth, and raises the tongue so that the water is driven through the mat, between the plates of whalebone, and out through the lips at the side. The plankton thus left stranded on the mat of whalebone fibres is then swallowed.

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When diving, the whalebone whales normally remain below for from five to fifteen minutes, and the toothed whales from thirty to sixty minutes, but all can greatly prolong their submergence if necessary. The deepest measured dive of a Fin Whale was over 350 metres, and there is some evidence of a Sperm Whale diving to 900 metres. When a man descends in a diving suit, air is pumped down to him at a pressure slightly greater than that produced by the column of water above him; the nitrogen in the air dissolves in his blood and tissues until, if he remains long enough under sufficient pressure, they are saturated. On ascending towards the surface the pressure decreases, and his blood and tissues are then super-saturated: the excess gas appears as bubbles which block the smaller blood-vessels and accumulate in the tissues, producing caisson sickness, or 'bends.' If the release of pressure is sufficiently great and quick, intense pain is produced and death may rapidly occur. When a diver has been for some time at considerable depths, his return to the surface must be gradual to allow the excess gas to be washed out of his tissues and prevent his becoming a living soda-water bottle. How is it, then, that whales can take sufficient air down to allow long-continued activity, and how are they able to avoid being killed by caisson sickness? The subject is not yet completely understood, but the latest work of the Whale Research Institute at Oslo has thrown much light on it. Several factors are concerned in prolonged diving. During diving the metabolic rate of the whale is reduced, so that the oxygen consumption of the body is greatly lessened—perhaps to only about 30 per cent. of the normal rate. The myoglobin of the muscles may contribute as much as one-third of the total oxygen store of the body, and the complex networks of blood-vessels—the *retia mirabilia*—act as an arterio-venous shunt so that the circulating blood bypasses the muscles during the dive. And, finally, the amount of oxygen removed from the air during breathing at the surface is unusually high. As for deep diving and caisson sickness, the whale takes down only the gases dissolved in its tissues and the air in its lungs, in contrast to the human diver who is supplied with a constant stream of air and is filling and emptying his lungs continually while below. The safety of the whale at great depths depends upon the lungs becoming so compressed that the air is driven out of the absorbing part of them. At a depth of 100 metres the compression of the whale's lungs is so great that the alveoli, where gaseous exchange takes place, are completely collapsed, and all the air is driven into the rigid tubes of the bronchi, trachea, and nasal passages, where the invasion rate of nitrogen is negligible. The whale can then return rapidly to the surface without danger of suffering from air embolism.

Even primitive man appreciated the value of whales, as is shown by the bones sometimes found in ancient kitchen-middens and hut sites; in fact, a stranded whale must have been a godsend to dwellers near the coast, a position curiously reversed nowadays when the responsibility for removing such a malodorous object devolves upon the owners of foreshore rights. At first, doubtless, the supply of meat provided by a whale was its chief attraction, but for many centuries the main value of whales has been the oil which can be extracted from them. When man had achieved the building of seaworthy boats, sooner or later he was sure to discover that fortuitous strandings could be improved upon by deliberately driving whales ashore. This primitive way of hunting still survives in the Faroe and Shetland Islands, where to this day schools of Pilot Whales —a rather small species not exceeding thirty feet in length—are annually driven ashore to the number of some hundreds and are there slaughtered, cut up, and boiled down for their oil. During the middle ages the Basques carried on a profitable fishery by putting to sea in small boats to hunt and capture the rather slow-moving and coast-frequenting Atlantic Right Whales, with such success that they practically exterminated them on their coasts. They did not drive the whales ashore, but evolved the technique of harpooning them with barbed spears attached to the boat by a line, and playing them until they were so exhausted that they could be approached and killed by stabbing with a lance. The dead whales were towed ashore for cutting up.

When the numbers of whales declined through over-fishing, these enterprising men fitted out ships to go further afield in search of their quarry. The base of operation was thus merely transferred from shore to ship, for the actual hunting was done as before in small boats lowered from the vessel. Before long, the Right Whales were so rare off the temperate coasts of Europe that lengthy voyages into high latitudes grew to be the regular practice. Here the whalers found a further reward for their boldness, for within the Arctic circle they discovered another sort of whale, the Greenland Right Whale, which yielded a greater quantity of oil than any other. Throughout

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the seventeenth and eighteenth centuries a large fleet of whale ships—French, Dutch, English, and Scandinavian—was regularly engaged in whaling voyages to the north, some ships boiling out their oil ashore at such places as Spitsbergen, Jan Mayen, or Bear Island, but others merely casking the blubber after cutting it into small pieces, and bringing it back to be boiled out at home. After the early part of the nineteenth century, northern whaling steadily declined, for Greenland whales were becoming scarce, and towards the end it was only the high value of the whalebone which kept it going. The extinction of the crinoline, together with the substitution of steel busks for whalebone in corsets, dealt the final blow at the industry; so that since the opening years of the twentieth century sailing ships have no more gone hunting the Right Whales of the Arctic.

On the New England and Connecticut coasts of America a similar evolution of whaling took place during the eighteenth century, but it was directed not only towards the Right Whales of the Arctic but also to the Sperm Whales of temperate and tropical seas. During the first half of the nineteenth century a very large fleet of Yankee whalers sailed the seven seas; but the civil war and the development of the petroleum industry started the ruin of American whaling, and the first decade of the present century saw the end of it. During the second half of the nineteenth century whaling voyages got longer and longer, up to five years away from home, during which time there would be visits in pursuit of Right Whales to the Arctic and Antarctic regions of both the Atlantic and Pacific Oceans, as well as months of cruising after Sperm Whales in the tropics. It was on these long voyages that the Americans developed the practice, adopted by whalers of other nations, of boiling out the oil on board ship in tryworks built on deck. The tryworks were a series of cauldrons set in brickwork, and the fuel used was the oil-soaked fibrous scrap remaining after the oil had been boiled out of the blubber. In spite of the danger of boiling such inflammable material on the deck of a wooden ship while at sea, there was not an unduly high loss of ships from fire.

The whaling carried on by means of harpoons hurled from small boats lowered by sailing ships was confined to a few species of whales, mainly Right and Sperm Whales, because these are the only sorts which float when dead. Other and larger species were inaccessible to this kind of whaling, because they are so large and active that the danger of attacking them, and the difficulty of even approaching such swift-swimming animals, are too great. Further, when dead they sink and would drag down with them any boat rash enough to have 'got fast' to them. But the existence of great numbers of the larger kinds of whales, known collectively as Rorquals and individually as Blue, Fin, Humpback, and Sei Whales, all immune from attack by the whalers, attracted the attention of Svend Foyn, an inventive Norwegian, about 1860. Foyn, realizing that entirely new methods were required, produced a very large harpoon fired from a cannon mounted in the bow of a small steamer and attached by a stout rope. By using a steamer he got the speed required to approach the Rorquals, and the heavy harpoon with its thick whale line gave sufficient strength to hold them when struck. In addition he devised an explosive head for the harpoon, fused to explode a few seconds after it entered the whale, which was usually quickly crippled if not killed at once. When dead the whale sank, but was hauled to the surface by heaving in the line on a steam winch. On arrival there it was made buoyant by inflating it with air pumped in by means of a hose fastened to a pointed pipe plunged into the body cavity. The carcass could then be towed home to be cut up and boiled down at leisure. This method of whale-hunting is the basis of the modern whaling industry and is essentially that in use on a large scale at the present day. Foyn's methods of hunting were used in conjunction with shore stations—factories at the water's edge of a sheltered harbour—where the whales were hauled on land and the products extracted with the aid of machinery.

The exploitation of the hitherto untapped resources provided by the Rorquals led to the establishment of whaling stations, of which the management and practically all the skilled labour were Norwegian, in many parts of the world; while in the tropics the same methods were used for the pursuit of Sperm Whales. A prosperous industry became firmly established, though after some years a falling-away in the numbers of whales became obvious at some places.

At the end of the nineteenth century much attention was being turned towards the exploration of the Antarctic, the last remaining great unknown region of the world. In 1902–3 the Swedish South Polar Expedition's ship, the *Antarctic*, was under the command of the veteran whaler captain C. A. Larsen, who noted the abundance of whales in the Antarctic and the suitability of many of the islands of that region

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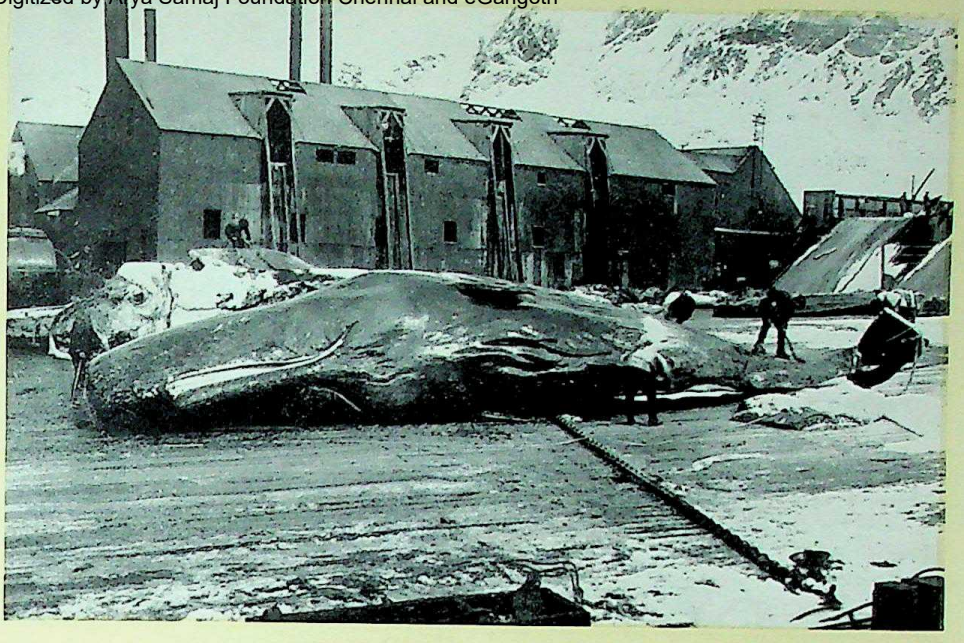

FIGURE 1 – *Ventral view of Sperm Whale on the flensing plane, showing factory buildings in the background.* (*Reproduced by courtesy of the Discovery Committee.*)

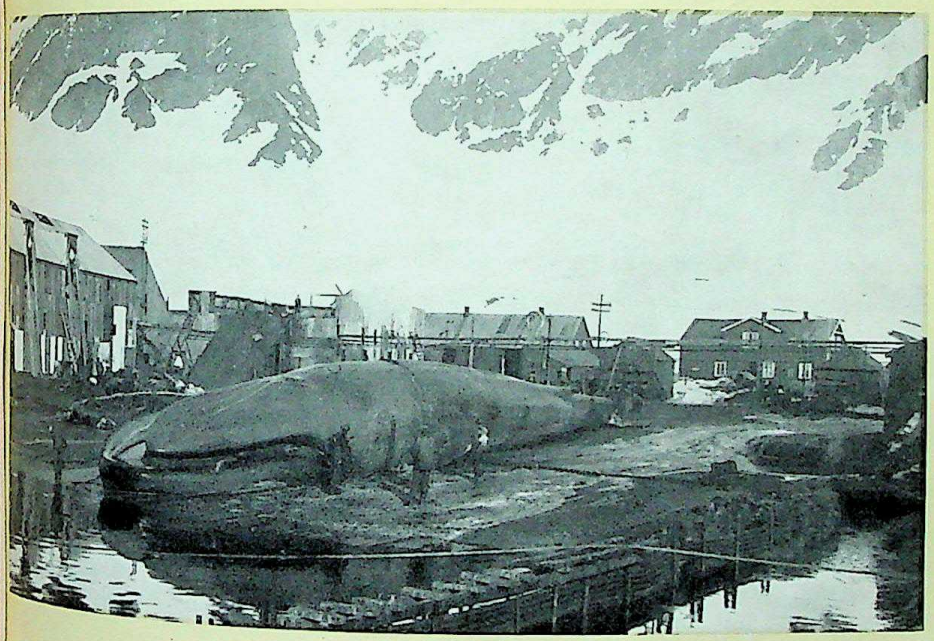

FIGURE 2 – *General view of Blue Whale, dorsal side uppermost.*
(*Reproduced by courtesy of the Discovery Committee.*)

FIGURE 3 – *A Fin Whale on the flensing plane at Grytoiken, S. Georgia.* (*Reproduced by courtesy of the Discovery Committee.*)

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FIGURE 4 – *Southern Right Whale, showing fin and baleen.*
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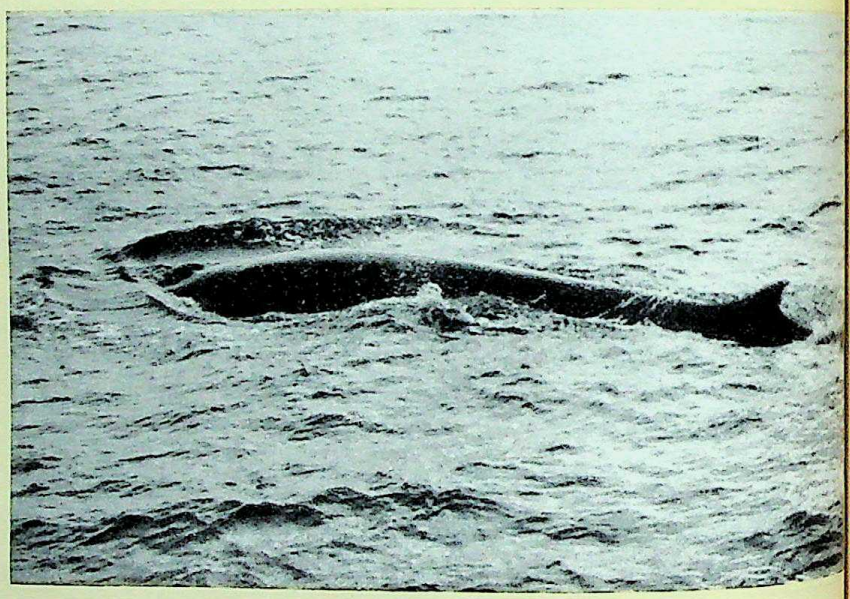

FIGURE 5 – *Whale breaking surface. Photograph taken from the* William Scoresby *during the season* 1934–5.
(Reproduced by courtesy of the Discovery Committee.)

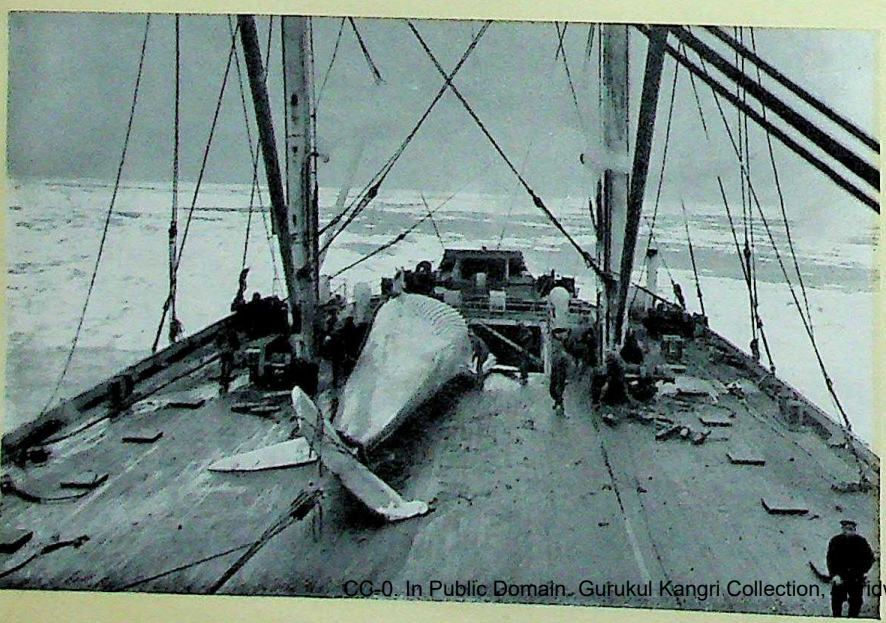

FIGURE 6 – *A factory ship showing a Blue Whale being hauled up the slipway to the flensing deck.*
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for the establishment of whaling stations. After his rescue and return (for the ship was lost) he found financial backing in South America to organize a whaling expedition on modern lines. In 1904 he started the first Antarctic whaling station in a sheltered cove on the island of South Georgia. Whales were abundant and the enterprise was a great success, paying a dividend of 70 per cent. in its first year; for the invention of the hydrogenation process for converting oils to fats had created a great demand for animal oils in the margarine and soap trades. Then started a rush for the new El Dorado, and within a few years a number of whaling companies were working on this island, and on the South Orkney and South Shetland islands farther south. The nearest inhabited country to these regions is a British Crown Colony, the Falkland Islands; and though the Antarctic mainland and islands had always been more or less a no-man's-land to the sealers, who were the only people to have used them since their discovery, Captain Cook had formally taken possession of South Georgia in the name of the British Crown when he discovered the island in 1775. The new activities in the south soon came to the notice of governments, and in 1908 Letters Patent under the Great Seal extended the boundaries of the colony of the Falkland Islands to include a large sector of the Antarctic continent, and its surrounding islands, which now form the Dependencies of the Falkland Islands.

As a result of territorial jurisdiction the British Government was able to introduce regulations to govern the whaling industry, in order to prevent an over-exploitation of the whale population and the consequent ruin of an important world-supply of raw materials. The regulations provided, amongst other things, for the issue of licences to engage in whaling, and the leasing of land on which whaling stations were to be built. They limited the number of hunting steamers or catchers, required whale carcasses to be completely utilized without waste, prohibited the killing of whale calves or their dams, and defined a close season. The application of the regulations was not difficult, because whaling could be carried on only from shore stations or floating factories—large ships provided with the necessary machinery for rendering down the whale carcasses cut up in the water alongside—both of which needed the shelter of harbours within territorial waters. The revenue derived from licences, leases, and a royalty imposed on the oil produced, provided a fund which was to be used for promoting the interests of the industry. In the course of time this amounted to a very large sum, which has been expended according to intention.

Soon after the start of southern whaling, the Government and its advisers saw the danger of repeating the mistakes made in the past in other parts of the world—as for instance in the Arctic, where over-fishing had ruined a once prosperous whaling industry. An Inter-Departmental Committee on Research and Development in the Dependencies of the Falkland Islands reported in 1920 that a rational regulation of the whaling industry demanded a full knowledge of the life-histories and habits of whales, and all that this implies, and recommended that scientific investigations should be started without delay. A scientific expedition in Captain Scott's old ship, the *Discovery*, was accordingly dispatched in 1925, and from that date until the present day scientific research in all parts of the Antarctic has been carried on by the Discovery Investigations Committee, using first this ship and then her successor, the splendidly equipped research ship *Discovery II*, and her smaller consort the *William Scoresby*. The results achieved have been of the greatest value, both to science and to whaling.

Before the *Discovery* researches began it had been assumed that whales grew slowly and attained a considerable age in reaching their full size. Among the first facts to emerge was the surprising one that they reach maturity quite quickly, and their full size at a comparatively early age. Of the many thousands of whales examined by the expedition, only one was found whose age was estimated at about thirty years, and the vast majority were not older than five or six. The largest species of whale is the Blue Whale, which when fully grown may reach a length of nearly a hundred feet; it is about twenty-five feet in length at birth and grows up quickly, reaching a length of over seventy feet, and being ready to breed, in two years. The period of gestation is roughly twelve months, that of suckling about six, and a further period of about six months elapses before breeding occurs again. The female Blue Whale thus produces a calf once every two years. The majority of the calves are born about the southern midwinter, but not in the cold Antarctic seas, for the whales have regular migrations and move north to temperate waters during the winter, and the young are usually several months old before they accompany their mothers to the south. The Blue Whale and a rather smaller species, the Fin Whale, which reaches sexual maturity at a length of about sixty

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feet and whose life-history is very similar, together make up the major part of the Antarctic catch; a third and smaller species, the Humpback, is of minor economic importance.

The southerly migration during the Antarctic spring and summer is entirely a feeding migration. The plankton of the south is very rich and is characterized by the presence of vast quantities of a crustacean much like a large shrimp—'Krill' or *Euphausia superba*—which there forms practically the whole diet not only of the whales but of many of the seals, penguins, and other members of the fauna. Whales quickly fatten on this food, and their blubber is conspicuously thicker and richer in oil soon after they reach the southern feeding grounds. The life-history of the helplessly drifting Krill is a complicated one. The eggs are laid near the bottom in deep water, 500–1,000 metres down, and the young when hatched drift in the current of comparatively warm water which flows south deep below the surface and wells up near the ice edge of the Antarctic continent. Here the adolescent Krill become concentrated and then drift north again in the cold Antarctic surface current, probably taking several years to become adult.

By about 1935, so much information had been accumulated about whales, their food, migrations, and the hydrological and meteorological factors governing their distribution, that it was evident that the whaling industry could with profit base its activities on this foundation of comparatively exact knowledge. But a new factor had now entered the problem of whaling, making the application of regulations to the industry as a whole impossible: this was the development of pelagic whaling. In 1925–30, when new whaling ventures could no longer obtain licences, the revolutionary move was made of fitting out a floating factory to operate entirely on the high seas, and to be completely independent of harbours. The many technical difficulties of such an undertaking were successfully overcome, and the advantages of being free from regulations, licences, and royalties, and of being able to cruise where whales were most abundant, were demonstrated. Once again the pioneering success was followed by many imitators, and there ensued an over-production of oil so great that the industry was forced to refrain from sending any expeditions south for a whole season, until the surplus was absorbed by the market.

The only remedy for this state of things was international agreement, and accordingly a conference of the interested nations met in London and drew up regulations for the industry. Each year the amount of oil to be produced is decided upon before the expeditions sail south, and the season during which, and the places where, whales are to be hunted are laid down. Hunting is thus confined to those regions where the whales are in best condition, and is prohibited in those where their exploitation is wasteful. It was hoped in this way to conserve the stock of whales so that an annual crop could be gathered safely, though a disquietingly high proportion of immature whales continued to be shown in the returns of the catches. All nations interested in whaling accepted the regulations except Japan; but Germany, though signing the agreement, did not observe it.

The modern pelagic whaler is a large ship of 20,000 tons or more, fitted with a ramp up which the dead whales may be hauled out of the water on to the flensing deck, where they are dismembered and the products extracted by the aid of elaborate machinery. She carries a crew of several hundred men and is completely self-reliant, having on board sufficient fuel for the factory and her attendant catchers as well as for steaming, and for distilling the large amount of fresh water required. Her chief homeward cargo is, of course, oil, which is used in the manufacture of margarine and soap, but, in addition, the whale meat and bones are used, after extraction of the oil, for producing feeding stuffs, guano, and bone flour. During the ten years before the late war the annual world catch has varied from 24,000 to 44,000 whales, producing from about 400,000 to over 540,000 tons of oil.

During the first season of the war the whaling fleet was in the Antarctic, but on their homeward voyages some of the ships were sunk and others were captured by the Germans, who managed to get at least one with her cargo safely into Bordeaux. Most of the remainder were thereafter used as oil fuel transports, and in that service many of them were lost. In the present season a diminished fleet is again at work, some of the ships being splendid new ones specially built for the purpose. The results of their hunting are awaited with interest, not only because of the universal famine of fats and other whaling products, but also for their biological importance. For the whales have enjoyed a close season of four to five years, and the effect of this on the numbers and individual sizes in the population will produce information not only of great scientific value but of fundamental importance to the whaling industry.

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Book reviews

MOULDS AND INDUSTRY

An Introduction to Industrial Mycology, by George Smith. Pp. xiv + 271. Edward Arnold & Company, London. Third edition, 1946. 20*s. net.*

The clinical success of penicillin and other antibiotics, the increasing industrial importance of fermentation processes, and the problem of preserving equipment from the attacks of micro-organisms have led many who possess little or no biological training to undertake the growth of moulds and the study of their metabolism. Such workers, among whom chemists are perhaps the most numerous, have an urgent need for an introductory book on mycology which is essentially practical in its outlook and is intelligible to the non-botanical reader. Mr Smith's book—first published in 1938 and now in its third edition—admirably meets this need. It is clear, it skilfully anticipates those questions which the beginner is most likely to ask, and it is illustrated with more than one hundred and fifty photomicrographs of exceptional merit. The first half of the book consists of descriptions and illustrations of the most common genera of moulds, emphasis being laid on those of the greatest practical importance. The remaining chapters are devoted primarily to accounts of laboratory methods and of the industrial significance of moulds. Besides numerous literature-references in the text, the book contains a useful guide to standard books and journals on mycology.

BRITISH BUTTERFLIES

Butterflies, by E. B. Ford. Pp. xiv + 368, with 48 coloured and 24 black-and-white plates. Wm. Collins Limited, London. 1945. 16*s. net.*

This stimulating and scholarly book is not for the mere collector of 'abs.' and 'vars.,' but will help the real student to discover facts which may be of permanent value in increasing knowledge of species formation, even among such hackneyed subjects as British butterflies. Dr Ford takes for granted the usual formal descriptions, and uses the biology of the insects as a basis for the discussion of several fundamental themes. Three of the fourteen chapters form an introduction to the theory of genetics; a subject on which the author is a recognized leader; they have a practical use in showing the lines along which results of value may be obtained. Much attention is paid to variation, and the field naturalist will be particularly interested in the chapter on evolution with its suggestive accounts of natural selection at work. The origin of the British butterfly fauna is discussed in the last chapter. There is a unique series of colour photographs of each species (alive in its natural surroundings), which is utilized to show points by which classification is aided. There are many other fine coloured or black-and-white plates, and maps showing the precise distribution of thirty-two species.

G. D. HALE CARPENTER

WIRELESS RECEIVERS

Radio Receiver Design, Part II, *by K. R. Sturley. Pp. xv* + 486. *Chapman & Hall Limited, London.* 1945. 28*s. net.*

The first part of this book was reviewed in ENDEAVOUR three years ago [1943, **2**, 162]. In this second part the author continues his detailed treatment of receiver design after the detector stage, but includes Automatic Gain Control and Automatic Frequency Correction as well as the general design features of audio amplifiers.

The reception of frequency-modulated signals is the subject of a separate section, in which a wide variety of demodulation circuits is well covered. All stages of television receiver design, from the aerial to the display, are dealt with in another section, in which the special characteristics required are given an authentic treatment.

Although the text is well supported by mathematics and calculations, these do not obtrude unduly into the explanations of physical principles. Altogether this book can be thoroughly recommended and fully bears out the promise of Part I. Each section is rounded off by a comprehensive bibliography.

S. JEFFERSON

NUCLEAR CYTOLOGY AND HEREDITY

Animal Cytology and Evolution, *by M. J. D. White. Pp. viii* + 375. *University Press, Cambridge.* 1945. 36*s. net.*

Dr White's book deals not with all aspects of animal cytology but exclusively with those which are most closely concerned in influencing the course of evolution, namely the constitution of the nucleus and, in particular, the organization of the chromosomes. There have, of course, been enormous advances in our knowledge of this subject since the appearance of the last great compendium on the subject, E. B. Wilson's *The Cell in Development and Heredity*. Many of these advances have been treated in Darlington's *Recent Advances in Cytology*, but even that work is already somewhat out of date, and it not only included botanical as well as zoological data, but was at least as much concerned with arguing the case for the author's theories as with a plain summary of knowledge. White's book therefore fills what has been something of a gap in the literature, and will be a most valuable work of reference for some years to come.

Dr White makes little attempt to develop any general theories of his own, and his book may therefore seem somewhat scrappy to readers not well acquainted with the field. Its merit is that it makes a practically complete survey of the data, and brings together in convenient form many of the rather out-of-the-way and peculiar phenomena which occur in certain groups. These examples enable Dr White to point out the weak places in some of the current theories, and his review is a great deal more than a mere catalogue, since his commentary contains many suggestions and criticisms of great interest and cogency.

C. H. WADDINGTON

CRYSTALLOGRAPHIC ANALYSIS

Chemical Crystallography, *by C. W. Bunn. Pp. xii* + 422. *Clarendon Press, Oxford.* 1945. 25*s. net.*

In the last few years crystallographic methods have been increasingly recognized as valuable aids in a variety of types of chemical investigation, but their wider use has been delayed by lack of general knowledge of the actual techniques and theoretical background required for their use.

Mr Bunn has set out to remedy this lack. He has written a very welcome—and a very readable—book designed to introduce the reader to the ideas and methods of crystallography as they can be employed in the study of chemical problems. The book covers a very wide field, from the examination of crystal morphology and refractive indices—most valuable in the routine recognition and identification of chemical substances—to the detailed X-ray analysis

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of complex organic compounds by Fourier methods. There are chapters on X-ray powder methods, the measurement of unit cell dimensions, and the determination of atomic positions, all illustrated by a large number of excellent examples. There is also a description of one of the most recent advances in technique, namely the use of optical diffraction effects in structure analysis. The deviations in structure and texture of crystalline materials responsible for broadened X-ray reflections are also discussed.

As is necessitated by the broad scope of the book, the treatment of individual topics is not exhaustive. The serious student who wishes for more detailed information will nevertheless find very adequate guidance from the references quoted, and, as a whole, Mr Bunn's book should certainly encourage his readers to look farther into the subject. The illustrations are numerous and very well designed.

One misprint may give a little trouble. The formula on p. 158 should read:

$$\tan \delta = \frac{\cos \alpha^x - \cos \beta^x \cos \gamma^x}{\cos \beta^x \sin \gamma^x}$$

D. CROWFOOT

THE SEA AS AN ENVIRONMENT FOR LIFE

Recent Advances in the Chemistry and Biology of Sea Water, *by H. W. Harvey. Pp. viii + 164. University Press, Cambridge.* 1945. *10s. 6d. net.*

In 1928 Dr Harvey rendered great service to all interested in the sea as an environment for life by the publication of his *Biological Chemistry and Physics of Sea Water.* He has now summarized the growth of knowledge since that date in this shorter, but no less valuable, book. The advances in this short period, from which the war years must largely be deducted, are very significant despite the small numbers of workers: a handful in this country, a few in the maritime countries of Europe, and rather more in the United States. It is noteworthy how very much of this work has been initiated at the Plymouth Laboratory of the Marine Biological Association by Dr Harvey himself and by Dr W. R. G. Atkins and Dr L. H. N. Cooper. It is sufficient to say of this book that it is written by a master of his subject; it is condensed and is essentially a work of reference, but in the last, and longest, chapter the reader will find the best available account of the factors underlying the general fertility of the sea, a topic which leads from the fundamental research of the chemist and physicist to the practical issues of productivity in terms of the supplies of fish for human consumption. C. M. YONGE

FLORA AND FAUNA OF LONDON

London's Natural History, *by R. S. R. Fitter. Pp. xii + 282, with 52 illustrations in colour. Wm. Collins, London.* 1945. *16s. net.*

Mr Fitter has written a delightful book, full of out-of-the-way information. The area he covers is that within twenty miles of St Paul's; and in spite of the spread of houses, this is a very wide field for one whose theme includes all branches of natural history. Indeed, the spread of houses in some respects extends the field, as animals and plants introduced by man come within the author's scope. Inevitably, therefore, much has had to be left out. The fish, for example, get rather patchy treatment, and no mention is made of even such a curious sight as that of gulls catching small pope in the waterworks near Molesey and dropping them again, apparently unhurt, on the paths around.

The material is arranged by periods, the first six chapters covering those from pre-Roman times to the middle of the nineteenth century. Thereafter Mr Fitter is concerned with the modern period, in which he considers such topics as 'nature indoors' (lice, rats, etc.), the built-up areas (which offer such pleasant diversions as a discussion of the recent colonization by black redstarts), and the influence of trade, traffic, water supply, refuse disposal, farming, sport, and finally war. The last has resulted in a remarkable growth of plants upon bombed sites.

Altogether this is a very readable and useful book, in which Mr Fitter, who is primarily an ornithologist, shows an admirable grasp of natural history in general. The coloured photographs are not altogether satisfactory, the colour sometimes being far from natural, so that in many cases the monochrome illustrations are preferable. IOLO A. WILLIAMS

A MODERN AID TO NAVIGATION

The Gyroscope and its Applications, *edited by Martin Davidson. Pp. 256. Hutchinson's Scientific and Technical Publications, London.* 1946. *Price 21s.*

It is known to most people that the gyroscope is used as the basis of a compass which is not affected by the proximity of magnetic materials, and that it is used in stabilizing ships and aeroplanes. Dr Davidson has had the excellent idea of producing a book, written by himself and other specialists in the subject, in which theory and practice are both described. The editor provides as clear an account, illustrated by experiments, of the theory of gyroscopic motion and precession as can be expected without the use of spherical trigonometry and generalized dynamics.

The chapters which follow are of a more practical nature. The marine instruments — compasses, gyro-pilots, and stabilizers—are described by G. C. Saul, and the aeronautical ones—direction indicators, rate-of-turn indicators, gyro-verticals, and automatic pilots—by J. A. Wells and A. P. Glenny. In both sections there are drawings and photographs of the instruments. The writers seem to have overlooked few of the practical applications, and the book should be both comprehensible and of interest to any mechanically minded reader. J. H. AWBERY

CELLULOSE

An Introduction to the Chemistry of Cellulose, *by J. T. Marsh and F. C. Wood. Pp. xi + 525, with 145 figures, including 23 plates. Chapman and Hall Limited, London. Third edition,* 1945. *32s. net.*

The industrial importance of cellulose chemistry and the extensive and scattered literature relating to it make a comprehensive and well-documented textbook essential both for the research worker and for all those concerned with production. Since the first appearance of this book in 1938 there have been many developments in this field, and in successive editions the authors have incorporated much new material, though without deviating greatly from the original format.

As in preceding editions, the authors reveal a remarkably wide grasp of their very complex subject and, equally important, express themselves in a lucid and readable way. The text is supplied with comprehensive references to original literature and is very fully illustrated with plates and diagrams. The result is a summary of modern knowledge which will be invaluable to all those, both specialists and others, whose interests lie in this important field.

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ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

VOLUME V OCTOBER 1946 NUMBER 20

The method and scope of science

The Renaissance, especially that particular feature of it known as the Revival of Learning, was marked by the growth of a new independence of thought. The scholars, the poets, and the artists of Europe were no longer content to seek their inspiration in the teaching of the schoolmen, in ecclesiastical dogma, or in any of the modes and habits of the Middle Ages, then drawing to a close. The new intellectual adventurousness led men to shake themselves free of tradition and sent them back to the great thinkers of classical Greece and Rome.

It would, however, be incorrect to imagine that this new freedom was born fully grown. On the contrary, in its infancy it achieved little beyond the exchange of one set of authorities for another. The scholastic pedants might be despised or ignored, but the writings of Hippocrates, Plato, and Aristotle were at first accorded the same uncritical acceptance as had formerly been given to those of Abelard, Albertus Magnus, and Thomas Aquinas. The works of the great philosophers of antiquity were in fact received for a time as true in their entirety, instead of being subjected to that critical scrutiny without which real progress is impossible. There was indeed no lack of men able to develop logical arguments; but logical arguments based on false premises could lead only to false conclusions, even though the premises were drawn from Aristotle himself.

Nevertheless the first and most difficult step had been taken, and men gradually began to perceive that the very reasons which had led to the overthrow of medieval authority made it necessary also to question the infallibility of the more remote past. Their growing self-confidence restrained them from a too credulous trust in statements the truth of which they had not tested for themselves, however celebrated the source; and when this second stage had been reached the way was open for rapid advance.

In this issue we publish an article marking the four-hundredth anniversary of the birth of Tycho Brahe. Brahe made a contribution to science which reached far beyond his immediate work in astronomy, in which field it enabled Kepler to formulate the laws of planetary motion. He clearly recognized and stated that an essential preliminary to argument and the formation of theories must be the collection of relevant facts by observation or experiment. This experimental method was accepted by Boyle, Newton, and the other great natural philosophers of the age, and is essentially the same as the 'scientific method' so widely used today. This implies the investigation of natural phenomena by the observational and experimental collection of facts, and the use of these facts to form a theory. This theory is used in turn to make predictions which can be tested by further observations and experiments. If the predictions prove correct, then the pragmatic truth of the theory is the more firmly established; if the predictions are incorrect, then the theory must be modified, or even abandoned, in the light of new facts.

The scientist's readiness to jettison theories is commonly misunderstood by the layman, who regards it as a sign of weakness and confusion. Science, he says, is continually offering different explanations of phenomena, and the statement implies an unfavourable criticism. It suggests, in fact, that the teachings of science are unreliable because their mode of expression is variable. This is plainly a fallacy, but it is so widely held as to form one of the chief stumbling-blocks to the lay comprehension of science. Perhaps the best way to remove it would be to make clear that by 'explanation' the scientist means no more than 'description,' or, more precisely, description of the unfamiliar in terms of the familiar. When this point is made the rest is simple, for descriptions of

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the same phenomenon or set of phenomena may vary in degree of accuracy or completeness. A child might describe a cow as a four-legged animal which eats grass and gives milk, and the description would be a true one. To describe a cow as the mature female of wild or domestic cattle of the genus *Bos* is equally accurate, but both descriptions lack completeness. A scientific theory has similar limitations of accuracy and completeness, and when an old theory is abandoned in favour of a new one the reason is either that the old theory did not give an accurate description of the phenomena concerned or that it was found to be lacking in completeness. Now, in the description of nature, perfect accuracy and perfect completeness are unattainable ideals, but what the scientist tries continually to do is to approach these ideals more closely. The scientific method does not elevate its theories to the rank of dogma but rather classes them with test-tubes and balances as necessary equipment.

This scientific method has proved of immense value in all the physical sciences, and is largely responsible for the speed with which scientific knowledge has increased during the past three centuries. Today it is so universally used by men of science that its comparatively recent origin is difficult to realize. It is, however, imprudent to judge that the scientific method must necessarily provide a means of solving all kinds of problems outside the physical sciences. Powerful though it is, the method is neither omnipotent nor foreseeably likely to become so. Even within mathematics and the physical sciences it has its limitations. The differential equations of modern physics are often solved by intuitive rather than by rigorous methods. Heisenberg's uncertainty principle, which now seems to be of such wide application, suggests that a single set of observations, however precisely made, may be capable of several alternative interpretations, to any one of which is it possible to assign only a degree of probability. The modern physicist is inclined to abandon the idea that the future is inherent in the present.

The scientific method in its simple form has had to be modified when dealing with natural phenomena where many variables exist and where control experiments are impracticable. In such cases statistical methods have proved invaluable. Meteorology, subject of Sir Nelson Johnson's article in this issue, provides many problems of this kind. Recent work has led to great advances in methods of collecting data relating to such variables as pressure, temperature, humidity, and wind velocity; but in interpreting these data one must, for the present at least, be content with probabilities rather than with certainties. A modern weather forecast cannot claim to state what the weather will be: it states what the weather is likely to be.

It is, however, in the realm of qualities not susceptible of measurement of any kind that the scientific method—as far as it has yet developed—ought frankly to be recognized as inapplicable. An obvious example can be taken from the field of art. The scientific method can give a great deal of information on the chemical nature of pigments, on the wavelength of the light they reflect, and on similar factors, but it is wholly unable to predict whether a picture will have an aesthetic appeal to those who see it. Nor can the scientific method be of help in those problems relating to drama, literature, and the like, which involve qualities that cannot be measured and knowledge which is not communicable. In the wide field of human affairs the scientific method cannot be applied, even in the form of statistical analysis, to problems in which events are influenced by the philosophical values of goodness, truth, and beauty, and emotions such as patriotism, fear, or political conviction.

There are those who see in science the surest road to human betterment; there are, too, those who see in science the impending ruin of the world. Wherever the truth lies between these extremes, it is at least indisputable that science must have a profound and increasing influence on the future of man. It is therefore essential that those charged with the responsibility of making great decisions should clearly recognize not only the scope but also the limitations of science as it is now conceived.

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Some recent aspects of meteorology

SIR NELSON JOHNSON

In spite of the fact that the phenomena of weather have forced themselves upon the notice of man since the earliest times, meteorology is a young science, for it is only comparatively recently that circumstances have permitted an effective scientific approach to the subject. In this article are discussed the factors which for so long retarded the scientific study of the weather, and the main lines along which the subject is now being actively pursued.

From the time of the ancients up to the nineteenth century, philosophers attempted to explain the sequence of weather they experienced at a particular place. But it proved a complete enigma. There appeared no rhyme or reason in it, and the situation was epitomized in the well-known phrase—'the wind bloweth where it listeth.'

In the course of time, workers out of doors gradually found that certain aspects of the heavens appeared to presage rain or fine weather, and the folk-lore of the Shepherd of Banbury grew up. Most of these 'rules' covered only a few hours ahead, and while a small number of them possessed an element of truth, the majority were devoid of any foundation in either fact or theory. The reader who is interested in this particular aspect of the subject is recommended to read a book recently published[1] in which the Shepherd of Banbury, *et hoc genus omne*, are subjected to critical examination.

Observation at a single point is still perforce the only method of study in many instances. In such cases a statistical treatment of the data becomes necessary. With many meteorological elements, however, departures from the mean are so large that the mean deviation of the observed quantity is frequently nearly as important as the mean value itself.

Before leaving the case of the single observer, it may be noted that there are instances where 'single-observer forecasting' has to be practised even today, such as in an isolated ship at sea. Modern knowledge of pressure systems and 'fronts,' however, enables a meteorologist to achieve a moderate degree of success in the interpretation of his own observations, but it is never a method to be employed if reports from surrounding places can be obtained by any possible means. International collaboration and the use of radio fortunately render it comparatively rare for a meteorologist to have to attempt single-observer forecasting.

The invention of the barometer in 1643 and the discovery that atmospheric pressure is subject to variation were, of course, epoch-making events. They failed, however, to lead immediately to the advance in the dynamics of meteorology which might have been expected.

The true light first began to dawn when the step was taken of plotting the observations made simultaneously over an area. This did not occur until early in the nineteenth century, but it at once brought to light the relation between pressure and wind, and it showed the organic structure of the depression. It revealed it as a huge vortex, and paved the way for the mathematical treatment of two generations later.

But progress was still slow, since the collection of observations from an area was a formidable undertaking in those days. It was the invention of the electric telegraph about the middle of the century that revolutionized the position. It soon became possible to plot 'synoptic' charts covering a wide area every day. The international exchange of observations became a necessity, and the second half of the century saw much effort expended on establishing international co-operation on a sound basis.

Although forecasting was still largely empirical, the physical and dynamical study of pressure systems continued. The co-existence in depressions of warm air currents from equatorial regions and of cold currents from the Arctic was recognized, and mathematicians attempted to discover under what conditions two such currents in juxtaposition would remain stable. But it was not until the second decade of the present century that the Norwegian meteorologists Bjerknes, father and son, produced a theory that was satisfactory both physically and mathematically.

[1] G. Kimble and R. Bush. *The Weather* (Pelican Books).

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According to the Bjerknes theory, a depression develops at a point on the boundary between a warm and a cold air current. The warm air forms a bulge in the cold current and the centre of the cyclone occurs at the apex of this bulge, or 'warm sector.' The structure is seen in figure 1. The leading edge of the warm sector is known as the 'warm front' and is characterized by the warm air sliding up over the cold air along a sloping surface, the inclination of which to the horizontal is about 1/150. The trailing edge of the warm sector is the

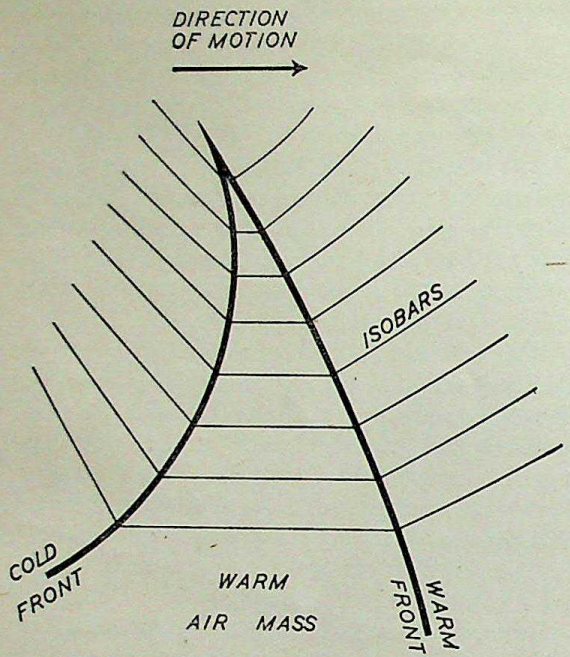

FIGURE 1 – *Structure of a depression (after Bjerknes).*

'cold front,' and here the cold air drives a wedge under the warm air, lifting it off the ground. The angle of the wedge is about 1/50. The combined effect of these two processes is to narrow the warm sector until eventually the whole of it has been lifted off the ground. From this point onward the depression diminishes in intensity.

The experience of the last thirty years has shown that the Bjerknes theory is a most valuable working hypothesis for the purposes of forecasting, and there seems little reason to doubt that it is correct in at least its essential features. For our present purpose its most interesting feature consists in the introduction of the vertical dimension. It is no longer sufficient to think of a depression as something happening close to the ground. Attention must be paid to what is occurring from sea-level up to the base of the stratosphere, and possibly within the stratosphere itself.

Although the need for information about the movement and physical conditions of the upper air was thus made apparent, it is only in the course of the last few years that means have been devised of obtaining this information on a routine basis. It is in this field of technique of observation that the most important advances have recently been made. A description will therefore be given of some of these new observational methods, together with an indication of the manner in which the information so obtained is used.

One of the most valuable pieces of upper-air information required by the meteorologist is a knowledge of the air movements aloft. Not only does it enable him to advise the aviator of the navigational wind which he will encounter, but it is also of prime importance in connection with the dynamics and persistence of both cyclones and anticyclones.

The normal method of measuring the upper wind is by following a pilot balloon by means of a theodolite. The method is, however, subject to the serious limitation that it cannot be used when the sky is clouded. Two methods have been developed which overcome this limitation. The first makes use of radio direction-finding, and the second employs the modern radar technique.

In the first method three radio direction-finding stations are set up on the ground in the form of a triangle of about 40 km. length of side. From a control station near the centre of this triangle a balloon of about 2 m. diameter is released, carrying a small radio transmitter. The balloon is filled with hydrogen to rise at about six metres per second, and its radio emissions enable it to be followed by the three direction-finding stations. The bearings of the balloon from each station are plotted every minute, the intersection giving its track, from which the wind speed and direction are immediately obtained. The balloon usually reaches a height of about 18 km. before bursting, when a parachute brings the transmitter down to earth again.

The direction-finding equipment employed at the three observing stations was developed by the National Physical Laboratory, Teddington. It consists essentially of an Adcock H-type aerial with vertical dipoles and capable of rotation about a vertical axis. The receiving circuit is tuned to the frequency of the balloon-borne transmitter, and the bearing of the latter is found by rotating the aerial until silence in the telephone shows that the aerial is normal to the incoming wave.

In order to secure accurate results by this

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method, strict attention must be paid to a number of points. Accurate symmetry in the construction of the Adcock H-aerials is, of course, essential, but precautions must also be taken to eliminate any possible refraction of the incoming radio beam. All iron must be rigorously excluded from the construction of the observing huts: there must be no metal fences, power lines, buildings, trees, or hedges in the vicinity, while the site must be level and possess a uniform subsoil.

These rather severe restrictions, combined with the fact that three observing stations are necessary, are gradually causing this method to give way to the radar method described below. During the past six years, nevertheless, the direction-finding method has proved of the greatest value and has yielded most important results.

In the second, or radar, method of wind-finding the course of a similar free balloon is again followed. In this case a radar transmitter at the observing station is used to direct radar pulses towards the balloon, which carries a special device for reflecting the pulses back to the radar receiving set. The receiving set is located beside the transmitter and gives measurements of the azimuth, elevation, and slant distance of the balloon. From these three quantities simple trigonometry enables the course of the balloon to be computed from minute to minute.

The actual form of the ground equipment is briefly as follows: the short-wave radar transmitter and receiver are housed in a lorry trailer, the emitting and receiving antennae being situated at the foci of two paraboloidal mirrors of 4 ft. diameter mounted on the roof. The two mirrors are carried side by side on a framework which can be rotated both in azimuth and elevation. The operator manipulates the system until a maximum strength of returned signal is received, showing that the axes of the two mirrors are directed at the balloon.

The special reflector carried by the balloon makes use of the principle of the 'corner reflector.' Three mutually perpendicular surfaces, such as are found in the corner of a box, possess the property of reflecting any incident beam back along its path. For wind-finding purposes, a reflector is made by stretching metallic paper on a light wooden framework arranged to form three intersecting surfaces—one horizontal and two vertical (figure 2). Although this reflector necessarily swings as it hangs below the balloon, its ability to turn a beam through 180° means that the radar pulses reaching it are always sent back at maximum intensity to the ground receiver.

The type of result given by the two methods of wind-finding just described is illustrated in figure 3, which shows the wind structure on 9th November, 1944. At noon on that day (graph *A*) the maximum wind speed occurred at a height of 10 km., with a value of 41 metres per second. By midnight (graph *B*) the wind velocity at the same height had increased to 102 metres per second (220 miles per hour). Until these modern methods of wind-finding became available wind velocities of this magnitude were not suspected, since they occur in cyclonic conditions when the sky is heavily clouded. Even more striking than the actual velocity, perhaps, is the rapidity with which the speed increased in the course of twelve hours.

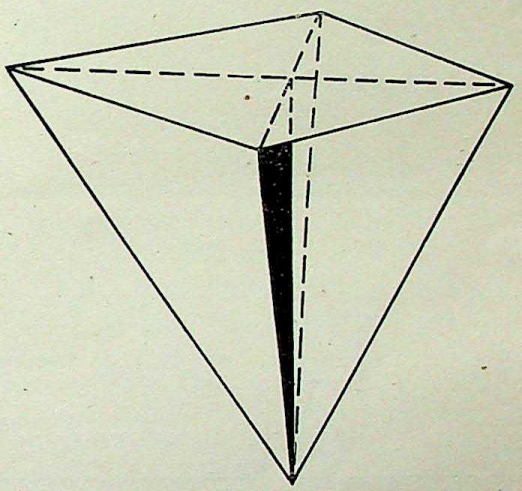

FIGURE 2 – *'Corner reflector' carried by balloon in wind-finding by radar.*

As already mentioned, these methods of wind-finding are at present limited to a height of about 18 km. During the war an opportunity occurred for measuring the wind at a height of 30 km. Although the method does not lend itself to routine use at stations generally, it has yielded results of unusual interest and importance. The method involves the use of a special gun, which fires a shell upwards at very high velocity. The shell is fuzed to burst at the vertex of its trajectory, and produces a smoke puff which can be followed by means of theodolites on the ground. A series of measurements made in south-east England at approximately fortnightly intervals over a period of fifteen months has shown that during winter the wind at a height of 30 km. is mainly westerly, while during summer it is predominantly easterly. The change-over takes place about April and October. It was further found that the winter

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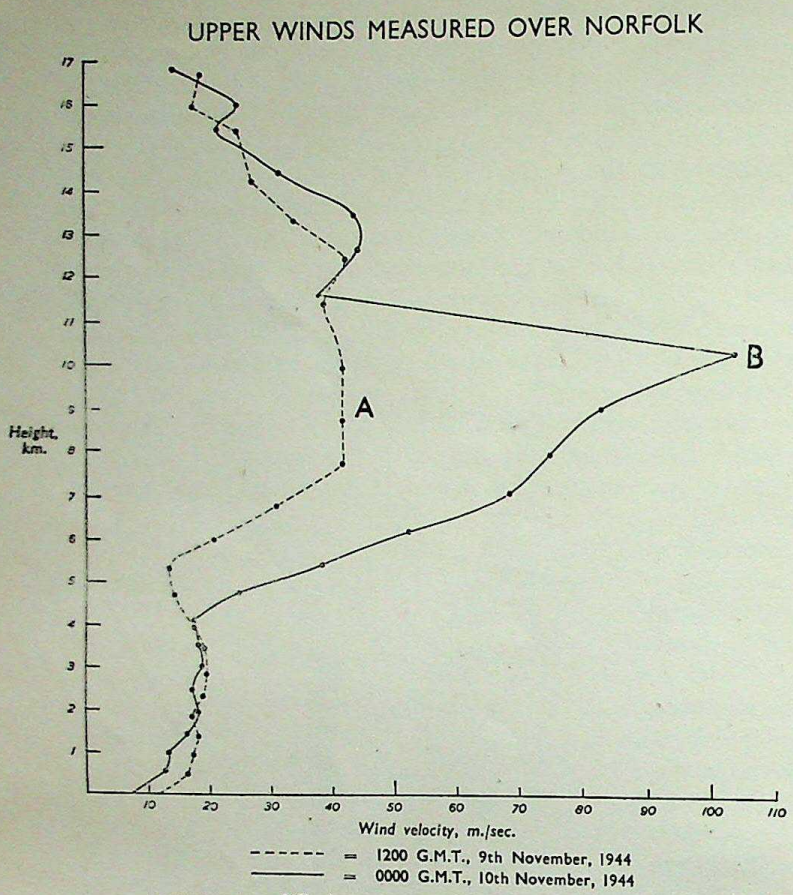

FIGURE 3 – *Wind structure at (A) noon and (B) midnight on 9th November, 1944.*

winds are much stronger than those of summer, the former averaging 37 metres per second and the latter only 12 metres per second. The greatest velocity observed during the period was 66 metres per second (147 miles per hour).

In addition to knowing the movement of the air aloft, the meteorologist also needs to know its physical conditions, i.e. its pressure, temperature, and humidity. This information is obtained by means of the radio sonde—possibly the most interesting of all meteorological instruments. Not only does it measure the properties just mentioned, but it automatically sends out radio signals telling the observer on the ground the values of these three quantities.

A radio sonde consists essentially of two main parts. First there are the meteorologically sensitive elements—one responding to the pressure, another to the temperature, and a third to the humidity of the atmosphere. The second part is the radio transmitter, together with mechanism for enabling variations in the meteorological components to impart corresponding variations in the radio transmissions.

Most radio sondes employ one of two principles. The first is the chronometric principle, which may be illustrated by reference to figure 4. Imagine an arm to rotate uniformly with a fixed contact at some point on the circumference; then contact will occur at regular intervals equal to the period of rotation of the arm. If now another contact is introduced, the position of which on the circumference is varied by a pressure-sensitive element, the time-interval between the fixed contact and the movable contact gives a measure of the pressure. If the circumference is divided into three sectors, one sector can be allotted to pressure variations (P), the second to temperature variations (T), and the third to humidity variations (U). Measurements of the pressure, temperature, and humidity can thus be obtained by observing the sequence of time-intervals. All that is necessary is to receive the transmitted radio message on a chronograph and to read off the time-intervals, which can be interpreted from the calibration chart for that particular transmitter. This principle has been adopted in the Canadian, Indian, and French instruments.

The other main principle employed in radio sonde design is that of causing the meteorological element to vary the frequency of the radio transmission. The frequency of an electrical circuit is determined by its capacitance, resistance, and inductance: the frequency can therefore be varied by changing any of these three quantities. In the Finnish instrument the capacitance of the circuit is varied; the American instrument varies the resistance; while the British instrument, of which the prototype was designed by the National Physical Laboratory, varies the inductance. There is, however, a minor difference between these instruments. Whereas the Finnish radio sonde varies the fundamental frequency of its transmissions, the other instruments produce variations in an audio-frequency modulation superimposed on the fundamental wave.

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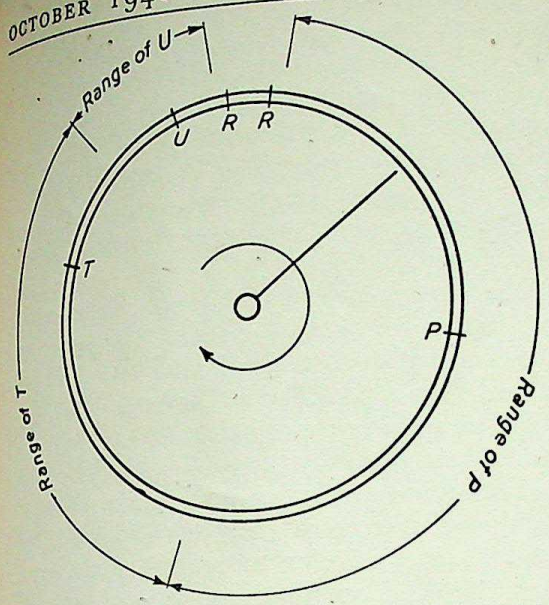

FIGURE 4 – *Chronometric principle employed in certain radio sondes.*

In order to illustrate how these principles are applied in practice, very brief descriptions will be given of the Canadian, Finnish, British, and American instruments. The first employs the chronometric principle; the other three depend upon frequency variation.

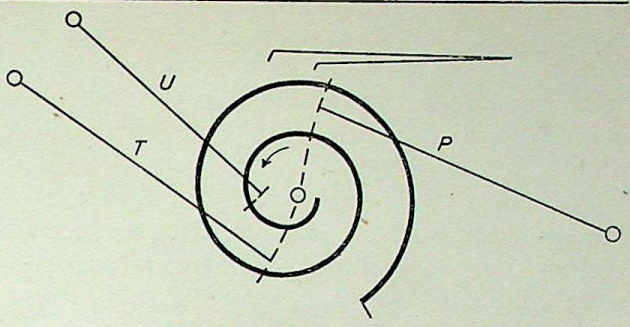

FIGURE 5 – *Chronometric unit of Canadian radio sonde.*

The central component of the Canadian instrument is a brass strip bent into the form of an equiangular spiral, which is rotated at a steady rate by a small electric motor (figure 5). The three meteorological elements are arranged around it, and each moves an arm carrying a fine contact wire at its end. The deflection of any of these arms from its normal position varies the time at which the contact occurs, and the latter can thus be made to indicate the former. Two fixed contacts placed close together are used to distinguish the reference point from the variable contacts.

The meteorological element for indicating pressure changes consists of an aneroid capsule, while for the temperature and humidity variations use is

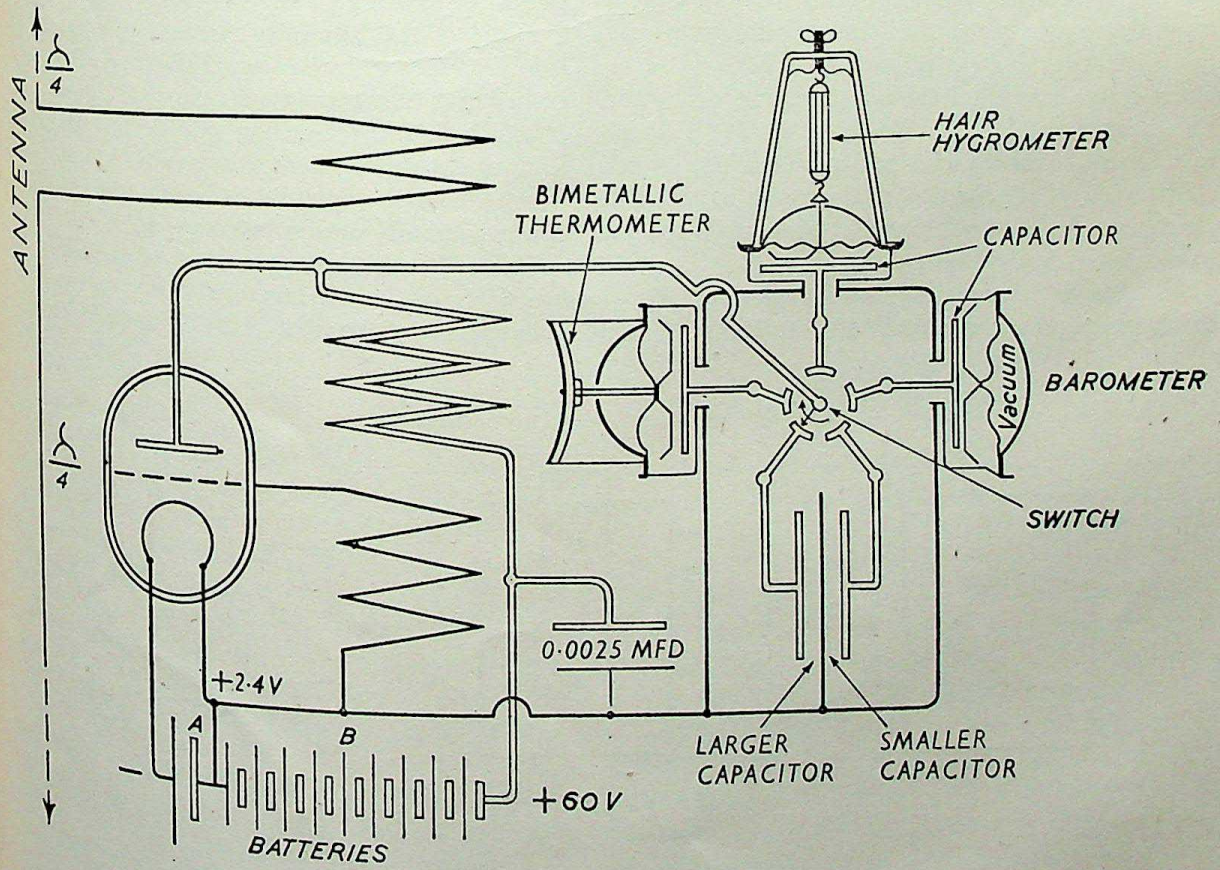

FIGURE 6 – *Arrangement of Finnish radio sonde (after Vaisala).*

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made of a bimetallic coil and hair respectively. The record is received at the ground on an ingenious chronograph which plots pressure, temperature, and humidity graphs directly against time.

The radio sonde designed by Dr Vaisala of Finland is an excellent example of the frequency-variation type of instrument. The general arrangement can be seen from figure 6. The meteorological elements are similar to those in the Canadian instrument, but in this case each carries one plate of a capacitor, the movement of which varies the capacitance, and hence the frequency, of the transmitting circuit. A windmill operates a rotary switch which connects each of the variable capacitors into the circuit in turn. There are also two fixed capacitors as reference marks. Incidentally, the Vaisala instrument is of very neat and compact design.

The British radio sonde resembles the Finnish instrument in general arrangement, but differs in two main respects. In the first place, each meteorological element is made to vary the inductance of an iron-cored winding, by moving an armature towards or away from the U-shaped iron core. The second major difference lies in the fact that in the British instrument the fundamental frequency of the transmissions remains constant, and the variations are produced in an audio-frequency modulation superimposed upon the fundamental frequency. As in the Finnish instrument, a rotary windmill switch is employed. A drawing of the British radio sonde is given in figure 7. It is about 19 cm. high and 14 cm. in diameter, and weighs $1\frac{1}{2}$ kg.

As already mentioned, the American radio sonde employs variations in the resistance of the electrical circuit. Pressure variations are indicated by a pair of aneroid capsules, which move an arm over a series of contacts. The temperature element consists of a fine glass tube filled with a non-freezing electrolyte. The conductivity of the electrolyte has a large temperature coefficient, and its resistance can therefore be used to indicate the temperature.

The American humidity element is also novel, and makes use of the variations in resistance of a film impregnated with lithium chloride when subjected to atmospheres of different humidity.

Before leaving these instruments, a few words upon their accuracy are called for. Much time and effort have been expended in discovering and removing sources of error in the British radio sonde. In particular the effects of the intense incoming and outgoing radiation at high levels have been investigated. These affect not only the meteorological elements but also parts of the electrical circuit. It is believed that the British radio sonde now gives temperature readings with an accuracy of about $\pm 0{\cdot}5°$ C. An accuracy of one millibar is aimed at in the pressure measurements. Although this represents only a tenth of one per cent. at sea-level, it becomes one per cent. at a height of about 15 km.

None of the humidity elements used on radio sondes can be regarded as satisfactory. The lag in response of hair becomes excessive at temperatures much below the freezing point. In the British instrument goldbeater's skin is now used, but even this, although appreciably better than hair, becomes virtually useless below — 25° C.

The only satisfactory method of measuring the humidity of the atmosphere at low temperatures is by means of the frost-point hygrometer recently

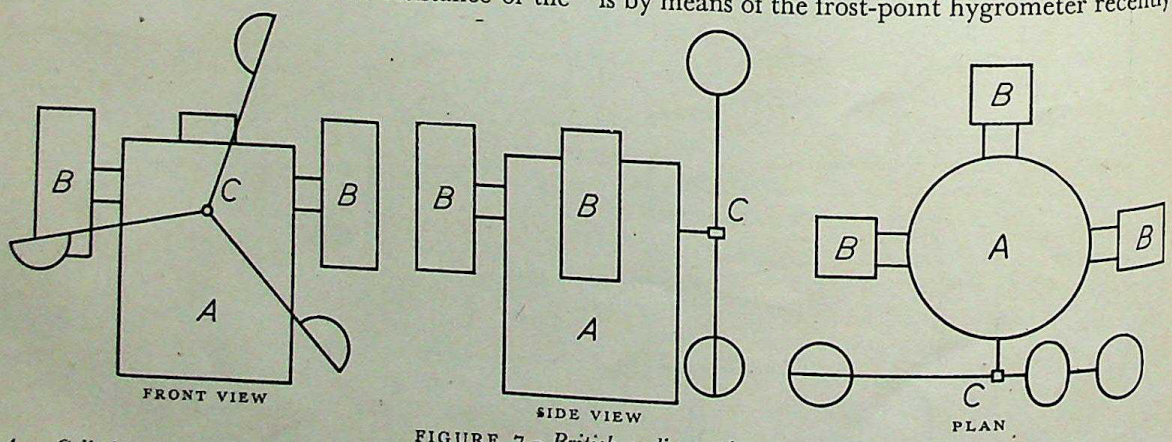

FIGURE 7 – *British radio sonde.*

A = Cylindrical body containing radio transmitter and batteries.

BBB = Radiation shields around pressure, temperature, and humidity elements.

C = Windmill operating rotary switch.

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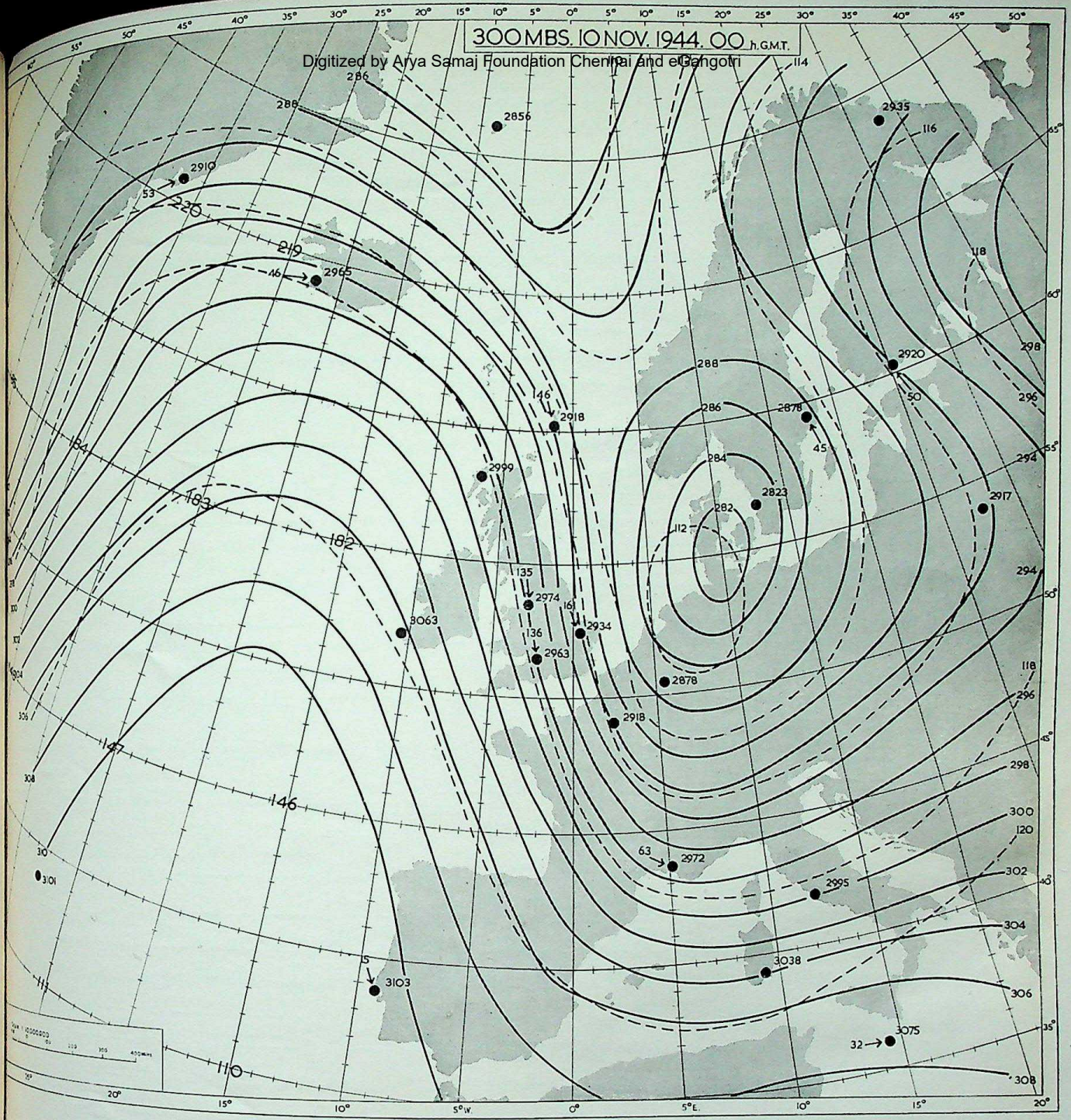

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FIGURE 8 – *Upper-air chart* (300 *mb.*) *for* 00 *h. on* 10*th November*, 1944.

For explanation see pages 135–6. The arrows and the (smaller) figures adjacent to them represent wind direction and velocity.

developed by Dobson and Brewer. Up to the present, however, the design has not been developed to a stage in which it can be used without an operator, and it cannot therefore yet be employed in a radio sonde.

The temperature encountered in the stratosphere may be as low as — 80° C, and at these temperatures the maximum quantities of water vapour that can be present are so excessively minute that their quantitative determination by most methods becomes impracticable. The depression of the hoar-frost point below the air temperature is, however, a quantity that remains reasonably large. Thus at a temperature of — 50° C the depression of the hoar-frost point for 50 per cent. relative humidity is about 5° C.

The principle of the Dobson-Brewer hygrometer is the same as that of the well-known Regnault dew-point hygrometer, in which a metal surface is cooled until dew forms upon it. The construction of Dobson's instrument is shown in figure 10. A copper thimble is mounted above a Dewar

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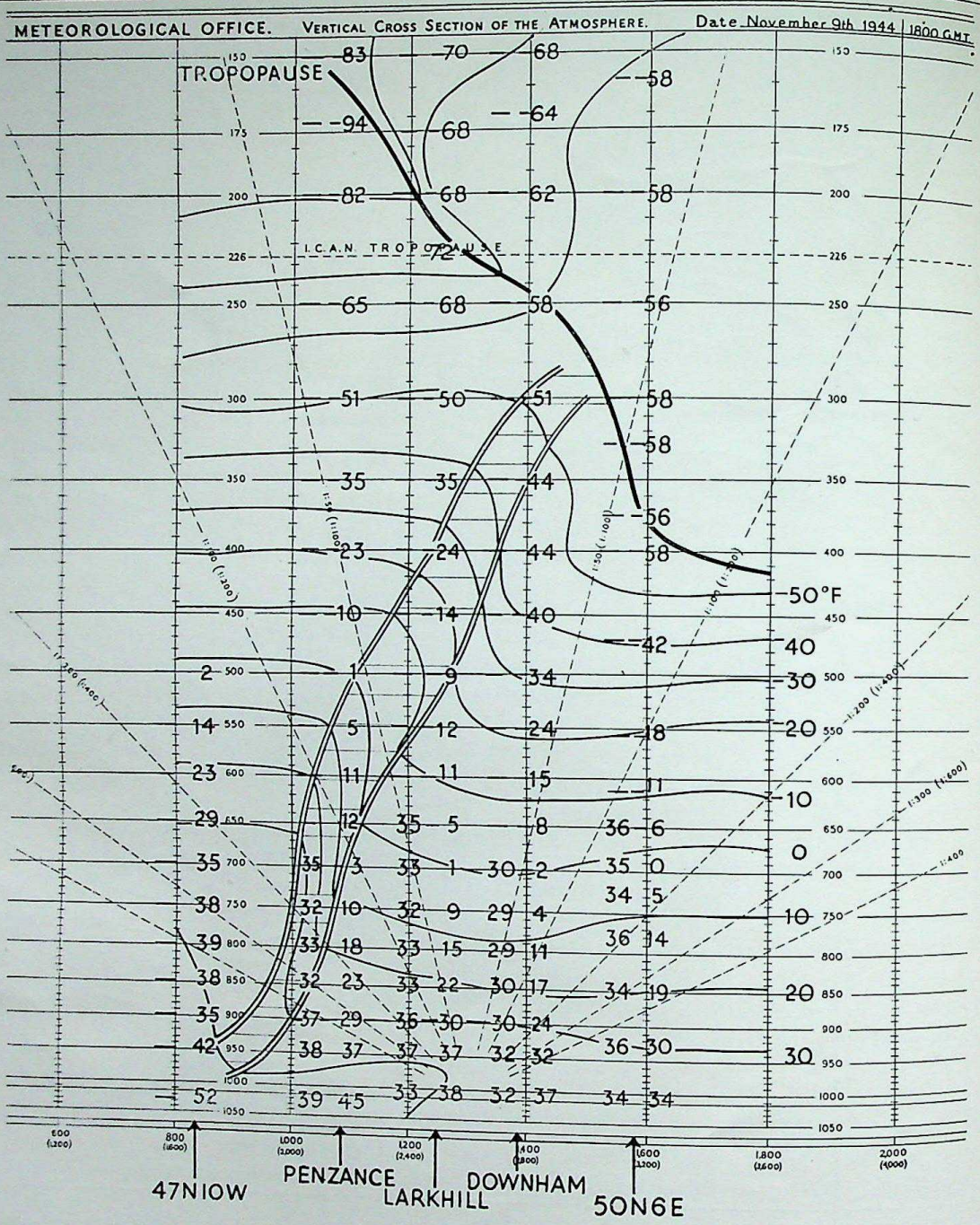

FIGURE 9 – *Vertical section of atmosphere for* 18 *h. on* 9*th November,* 1944.

flask containing petrol cooled by adding solid carbon dioxide. By means of a hand-operated pump the cold petrol can be made to impinge against the lower side of the thimble, on the upper face of which a deposit of hoar frost eventually forms. The temperature at which this occurs is indicated by an electrical thermometer embedded in the thimble. The formation of the deposit is detected by the aid of a photoelectric cell, which is found to be substantially more sensitive than visual observation. A beam of light is directed obliquely on to the upper face of the thimble, and the reflected beam is absorbed by a light trap. With the formation of a deposit of hoar frost on

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the thimble face, some of the light is scattered and is focused on to the photocell. In practice the temperature of the thimble is adjusted to give a steady reading of the photocell microammeter, showing that the hoar-frost deposit is neither growing nor evaporating. A small heating coil around the thimble facilitates the control of its temperature.

Mounted in an aircraft, this instrument has given excellent results in the hands of Mr Brewer, who has made many ascents into the stratosphere.

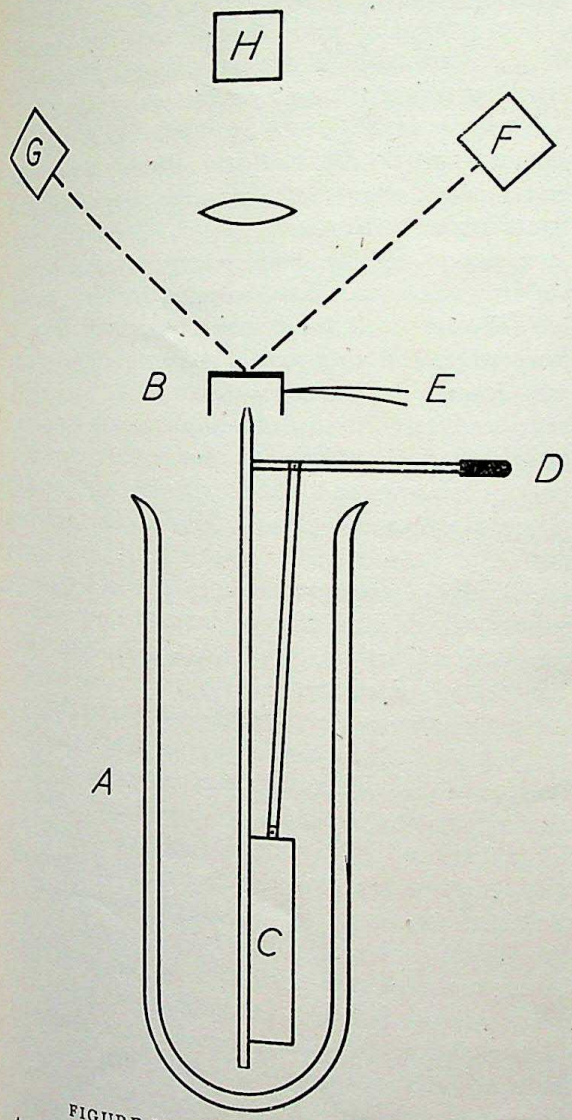

FIGURE 10 – *Dobson-Brewer hygrometer.*
A = *Dewar flask containing petrol cooled by solid carbon dioxide.*
B = *Thimble.*
C = *Pump operated by handle D.*
E = *Electrical thermometer embedded in thimble.*
F = *Light source.*
G = *Light trap.*
H = *Photocell.*

The most important result is the discovery of the fact that the air in the stratosphere is exceptionally dry. Up to the base of the stratosphere the relative humidity generally lies between, say, 30 and 100 per cent., but on entering the stratosphere the humidity falls rapidly, until at a distance of about 2 km. within the stratosphere the value is in the region of 1 per cent.

The height at which the stratosphere begins varies with the meteorological situation. In the latitudes of the British Isles the average height is about 11 km., but it may lie between about 8 km. and 16 km. The very low humidity mentioned above has been observed on occasions when the base of the stratosphere was at about 10 km. It is not yet known whether such low humidities occur when the base of the stratosphere is at greater heights. The low humidity is presumably due to subsidence of the air from the stratosphere in equatorial regions, in which case the lowest humidities would be expected only when the base of the stratosphere is relatively low in temperate latitudes.

In passing, this recent knowledge about the humidity in the stratosphere throws light upon a phenomenon which was observed in the early stages of the war. It was discovered that the 'vapour trails,' which were such a conspicuous feature of the sky around the time of the Battle of Britain, ceased to be formed if the aeroplane climbed into the stratosphere. It would perhaps be more correct to say that only short and faint trails were produced instead of the long and dense trails at lower levels. These vapour trails are formed by the condensation of the moisture in the exhaust gases from the aeroplane engine. It is now clear that the failure of dense trails to form in the stratosphere is due to the fact that the very low humidity causes the trail to evaporate almost as fast as it is formed.

It will have been noted that the aim of all the new observing techniques described above is to secure additional information about the upper atmosphere. It is now proposed to indicate briefly how the information so obtained is used.

The primary value of upper-air observations is for the construction of charts for the upper levels of the atmosphere, corresponding to the well-known synoptic charts for sea-level. In the latter, isobars are drawn for this standard level. In the case of the upper-air charts, however, the practice evolved in Britain is to draw isopleths showing the height of the surface of a selected value of pressure. The resulting charts are very similar in

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appearance to ordinary synoptic charts, a depression, for example, being represented by a series of concentric closed curves. A series of charts is drawn for the pressure levels of 1,000, 700, 500, and 300 mb. These correspond roughly to heights above sea-level of zero, 11,000, 18,000, and 30,000 ft. respectively.

The 1,000 mb. surface chart is first computed from the sea-level pressure readings. The thicknesses of the successive layers, 1,000–700 mb., 700–500 mb., and 500–300 mb., are then calculated from the upper-air temperature and humidity observations given by the radio sonde or aeroplane ascents. By adding these thicknesses successively to the 1,000 mb. chart, a series of contour charts is obtained for each of the pressure levels—700 mb., 500 mb., and 300 mb. Upper-air observations are made and charts are drawn every six hours, giving a sequence of charts which show the tendencies of temperature, thickness, and height of isobaric surfaces. Figure 8 shows the 300 mb. chart for the occasion referred to earlier, when a wind velocity of over 200 m.p.h. was recorded (see figure 3). These upper-air charts enable direct forecasts to be made of the wind, cloud, and other conditions in the upper atmosphere for aviation purposes.

The upper-air data are also used for drawing vertical sections of the atmosphere. Figure 9 is such a diagram and refers to the same occasion as figure 8.

In this type of diagram horizontal distances are plotted as abscissae, the position of each observing station being shown by its name or its geographical co-ordinates. The vertical scale is height, but is magnified two hundred times compared with the horizontal scale. Above each observing position are plotted two columns of figures. The right-hand column is the observed air temperature at successive heights (or pressure-levels), which enable the isotherms to be drawn. These are roughly horizontal in the right-hand portion of figure 9 but turn sharply upwards at the 'cold front' shown by the two steep double lines towards the left of the figure. Although a 'front' is usually spoken of as if it were a line, in practice the discontinuity is not sudden but is spread over a zone perhaps a hundred miles wide.

The left-hand column of figures entered above each observing position in figure 9 is the 'wet-bulb potential temperature.' This is a conservative property throughout any particular air mass, and it is therefore extremely valuable in identifying and locating the limits of air masses. The constancy of the wet-bulb potential temperature, both vertically and horizontally, to the right of the front in figure 9 will be noted. The height of the base of the stratosphere (i.e. the tropopause) is indicated by the heavy line towards the top of the diagram. The rapid change of height which occurs in the vicinity of the 'front' is noteworthy.

Figure 9 has been discussed at some length because it affords a good illustration of the detailed study which can be made of the atmosphere as a result of the new observing techniques.

These two types of upper-air chart (figures 8 and 9) provide a vivid three-dimensional picture of the structure of the atmosphere and of the air-mass movements which are taking place.

No account of the recent study of atmospheric processes would be complete without a reference to the work which is being done upon radiation equilibrium in the atmosphere. There are many facts about the upper atmosphere which cannot yet be explained. For example, it is not known why the temperature of the stratosphere is 50° C lower over the equator than over the poles, and why it varies considerably with time. The radiation conditions in the stratosphere are governed largely by such minor constituents as water vapour, ozone, and carbon dioxide and possibly other polyatomic gases. The solution of the problems just mentioned therefore requires a knowledge of the gases comprising the high atmosphere, the density of these gases at various levels, and their absorption coefficients for various wavelengths. Full understanding of the problems also involves knowing how such gases are formed and decomposed. These investigations clearly represent long-term fundamental research of a complex character, but solutions to them are essential for a rational understanding of the atmosphere and its ways, and they are being actively pursued under the guidance of the Gassiot Committee of the Royal Society.

In the foregoing review we have discussed three phases in the history of meteorology. In the first phase, the study of the subject was attempted from observations made at a single place. A great advance was made when it became possible to collect regular observations over an extended area and led to phase two. The third phase is characterized by a three-dimensional approach to the subject. The observational instruments necessary for such an approach have recently been developed. The third phase, however, is only just beginning, and it would be rash to predict how rapid further progress is likely to be.

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Tycho Brahe, 1546–1601

HERBERT DINGLE

The importance of precise observation in the formulation of theories is now so universally recognized that it is difficult to appreciate that it has not always been thus. Tycho Brahe's realization of the fact enabled him to accumulate the data essential for Kepler's expression of the planetary laws, an event which profoundly affected the future development of astronomy. His principles are, however, fundamental to the scientific method of today, and his teaching ultimately reached far beyond the astronomical field in which it was first applied.

The period known as the Renaissance was a critical epoch in many departments of thought and knowledge, and in none more so than in astronomy. The importance of this fact is greater than appears at first, for astronomy was so interwoven with the general texture of medieval thought that its reformation entailed a new outlook on life and on the world as a whole. Fortunately its development at this time is easy to trace and understand, at least in its broad outlines, for it was mainly the work of four men. The essential change of viewpoint was introduced by Copernicus, but Copernicus did little to take advantage of the opportunity he had created. He took the medieval vision with him to the modern viewpoint and saw the celestial spheres and the Ptolemaic deferents and epicycles enveloping the sun instead of the earth. Kepler was the first to show what possibilities lay in the Copernican reform, and his laws of planetary motion, in which spheres and perfect circular motion were finally abandoned, contained in essence the solution of the whole problem of medieval astronomy. Kepler's work would have closed the study of astronomy, except for a few minor adjustments, had not Galileo with his new mechanics and 'optic tube' given the subject a new life and opened up the limitless fields of inquiry which we are still exploring. To these three men we owe everything which we now possess in theoretical astronomy, but their work would have been essentially incomplete or impossible without that of a fourth. It is to Tycho Brahe that Kepler was indebted for the observations which enabled him to express the true planetary laws in Copernican terms, and this was not a mere accidental debt. The work of Tycho represented a new outlook, a change as radical in its way as that of Copernicus, for, surprising as it may seem now, the idea that before describing phenomena one should know as accurately as possible what those phenomena were, was almost unthought of in the sixteenth century. Tycho was thoroughly modern, and in his day almost unique, in realizing the value of precision in measurement, and Dreyer, his excellent modern biographer, opines that his accuracy 'but for the invention of the telescope could hardly have been much exceeded by his successors.' Certainly without Tycho's work there would have been no Kepler's laws, and possibly Newton would have been unable to formulate his law of gravitation.

Tycho Brahe (or Tyge Brahe, to give him his Danish name) was born at Knudstrup on 14th December, 1546. He was the second child and eldest son of Otto Brahe, a privy councillor and member of an ancient noble Danish family, and his wife, Beate Bille. He was brought up by his uncle, Jörgen Brahe, who, being childless, had, partly by force and partly by persuasion, succeeded in obtaining charge of him. After preliminary education under a tutor he went, at the age of 12, to the University of Copenhagen, and studied rhetorics and philosophy with a view to becoming a statesman. A partial eclipse of the sun on 21st August, 1560, however, profoundly impressed him, and he thought it 'as something divine that men could know the motions of the stars so accurately that they could long before foretell their places and relative positions.' He immediately began to study the subject, and bought a volume of the works of Ptolemy which seems to have absorbed his interest during the remainder of his three years' study at Copenhagen. This aberration somewhat disturbed his uncle, who, on sending him to a foreign university according to custom (Leipzig was chosen for Tycho), sent with him as tutor a young man, Anders Vedel, whose duty it was to see that his studies were such as befitted a nobleman. Vedel—who subsequently attained distinction as a historian and remained a lifelong friend of Tycho—

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tried conscientiously to fulfil his obligations, and at first Tycho had to study astronomy and mathematics while Vedel was asleep. After some remonstrances, however, Vedel was forced to acknowledge that Tycho was born for astronomy and for nothing else, and a tacit working arrangement seems to have established itself. When only 16 years of age, says Dreyer, 'his eyes were opened to the great fact, which seems to us so simple to grasp, but which had escaped the attention of all European astronomers before him, that only through a steadily pursued course of observations would it be possible to obtain a better insight into the motions of the planets, and decide which system of the world was the true one.' His first observation was of an approaching conjunction of Jupiter and Saturn, made with a pair of ordinary compasses on 17th August, 1563, but he soon set about acquiring a better instrument. In the following year he secured a 'radius'—two graduated rods of which the longer bisected the shorter at right angles and could move in its own direction so that, sights being fixed at each end of the shorter rod and at one end of the longer, a position could be found in which the eye, placed at the last-named sight, could see through the others two stars whose angular separation was to be learned. This did not satisfy him, but, being unable to get money from Vedel for a still better instrument, he made observational history by constructing a table of corrections to its readings.

Tycho's uncle died shortly after his return to Denmark, and, his relatives looking with disfavour on his odd interests, he soon left again for Wittenberg and later Rostock, where, in a famous duel, he lost his nose and made for himself an artificial one of gold and silver. In the meantime, however, his astronomical pursuits were not entirely discountenanced at home, and on 14th May, 1568, King Frederick II of Denmark granted him the next vacant canonry—a sinecure which would afford him means of continuing his astronomical work in his native country. Nevertheless, more than two years elapsed before he returned—years in which at Augsburg he constructed, with his friends the brothers Hainzel, a quadrant with a radius of 14 cubits (about 19 ft.), a sextant, and a celestial globe 5 ft. in diameter. For some reason he did not immediately continue this work in Denmark but turned his attention to alchemy, until, on leaving his laboratory on 11th November, 1572, he noticed an extremely bright star in Cassiopeia where, as he well knew, no such star was wont to appear. Doubting his senses, he appealed to some neighbouring peasants for confirmation, and when the reality of the star could no longer be questioned he at once proceeded to measure its position. From then onwards Tycho never allowed his interest in astronomy to lapse. He constructed instruments, introduced devices to make them foolproof, determined their errors, and gave the limits of accuracy of the results—a procedure in observation which was unique in his day. Its importance in this case was that Tycho established beyond question that the parallax of the star was too small for it to be as near as the planets, and it must therefore belong to the sphere of the stars whose immutability had been a cardinal principle of astronomy from the earliest days. Nothing but observations of which the degree of exactitude was high and was known could have placed this momentous fact beyond question. Later, when a comet appeared in 1577, he was able to show by precise measurements that it must have passed through the material of the spheres, if these existed, and another ancient illusion was shattered.

After completing his work on the new star, Tycho travelled extensively in central Europe, finding in particular a kindred spirit in the Landgrave Wilhelm of Cassel, an astronomer of no mean ability. It was through the Landgrave that King Frederick realised fully what a remarkable subject he possessed, and when Tycho, during a short visit to his native land in 1576, was planning to settle permanently in Basle, the King made him such a munificent offer that he altered his plans and decided to remain. The chief part of the gift was the island of Hveen 'with all our and the Crown's tenants and servants who thereon live, with all rent and duty which comes from that, and is given to us and to the Crown, to have, enjoy, use and hold, quit and free, without any rent, all the days of his life.' There were also sums of money for building an observatory, and various sources of income involving little more than nominal duties. The offer was too good to be refused, and at the end of May Tycho began to build the observatory which was to be his home for more than twenty years and at which the greater part of his work was done.

Space prevents a detailed description of what must have been a most palatial observatory even by modern standards. The illustrations give a general idea of the layout. The main building, known as Uraniborg, was nearly in the centre of the island and was built in the Gothic Renaissance style then becoming popular. It was at first the only

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FIGURE 1 – *Tycho Brahe, from a portrait at the Royal Observatory, Edinburgh.*

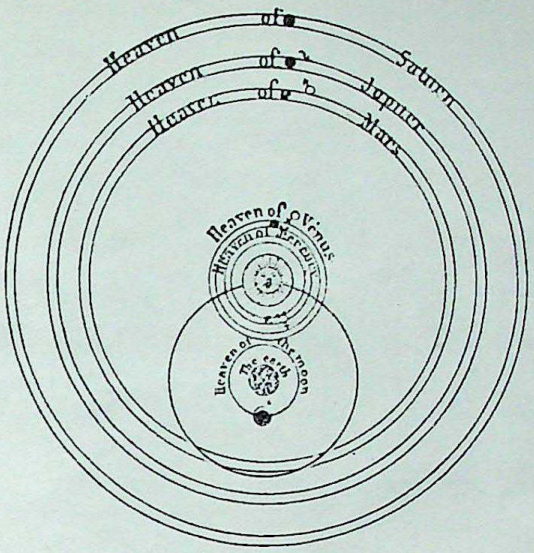

FIGURE 2 – *Tycho Brahe's astronomical system. The earth was stationary, and the moon and sun travelled round it. The other planets travelled round the sun and therefore with it circled the earth.*

Illustrations from Tycho Brahe, *by J. L. E. Dreyer, published by A. & C. Black Ltd.*

astronomical building, but in 1584 a second observatory was erected to the south, known as Stierneborg. To this island astronomers from all over Europe came to work with Tycho, and the work done there is the basis of modern astronomy. Tycho's innovations consisted first in the great size of his instruments; secondly in his improved method of graduation—he was the first astronomer to use the method of *transversals* in which the main graduations were made alternately on each of a pair of parallel arcs, successive marks being joined diagonally so as to form a zigzag pattern (see, for example, figure 4); thirdly in a greatly improved method of constructing and arranging his 'sights'; and, finally, in the practice already mentioned of determining as precisely as possible the errors of his instruments. His most outstanding contributions, in addition to the destructive ones already mentioned (to which may be added the final disproof of a long-maintained belief in a false movement of the stars known as *trepidation*), included far more accurate observations of the positions of the heavenly bodies than any previously made, the first observations of the effect of atmospheric refraction on apparent positions, and the discovery of the third and fourth inequalities (known respectively as the *variation* and *annual equation*) in the moon's motion as well as the fluctuation in the inclination of the moon's orbit to the ecliptic. Tycho differed from all his predecessors in making his observations in a systematic manner. Whereas it had been customary to make occasional observations of the positions of the planets, Tycho observed them regularly and systematically before and after opposition. This systematic observation, combined with the care and accuracy with which the observations were made, enabled Kepler to deduce his three laws of planetary motion and so to lay the foundation of celestial mechanics. These laws could never have been deduced from a few observations made near opposition.

In general, Tycho was less concerned with the interpretation of his observations than with their acquisition; it was left to Kepler to show what an abundance of knowledge they enshrined. He was anything but indifferent, however, to the great question of the day—the decision between the

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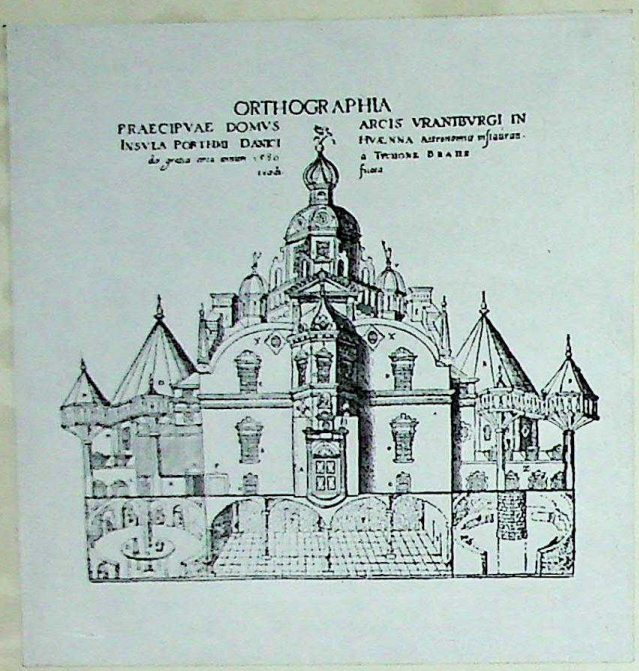

FIGURE 3 – *Uraniborg from the east The N.–S. distance is about* 100 *ft. and the greatest height* 62 *ft.*

FIGURE 4 – *The great mural quadrant at Uraniborg. This instrument consisted of a brass arc of* $6\frac{3}{4}$ *ft. radius, divided by transversals and screwed to the wall, on which were painted a portrait of Tycho and some of the wonders of Uraniborg.*

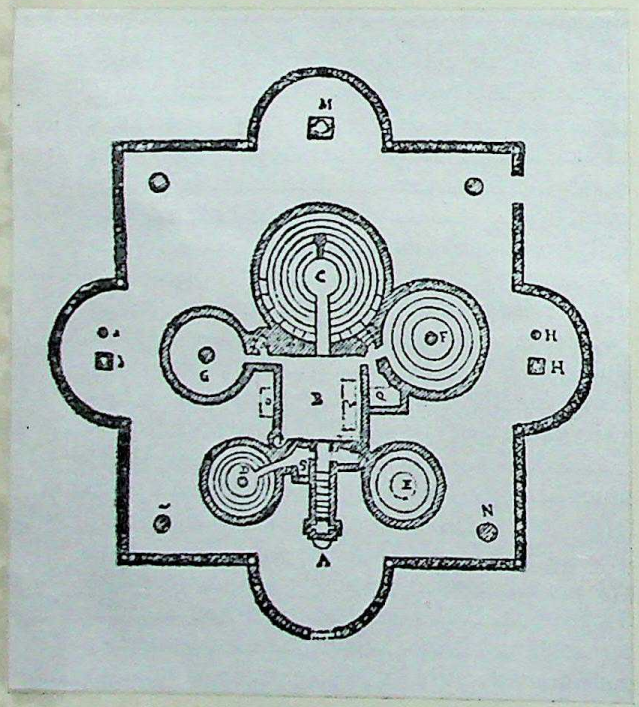

FIGURE 5 – *Plan of Stierneborg. C, D, E, F, and G are subterranean rooms with only the roofs above ground, to protect the instruments from the wind. O and Q are bedrooms for Tycho and an assistant, and S is an unfinished subterranean passage towards Uraniborg.*

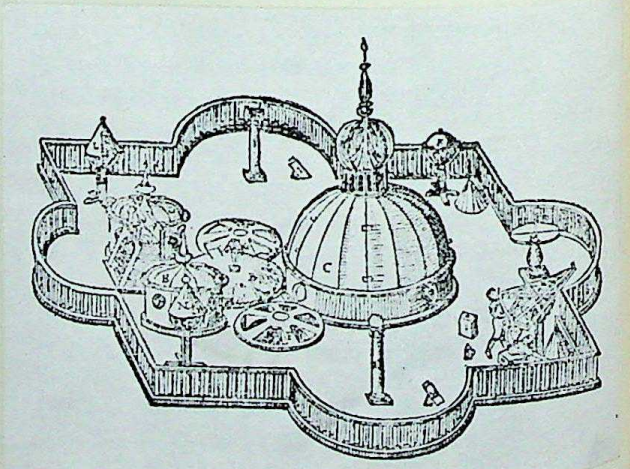

FIGURE 6 – *Stierneborg from the west. This and figures* 3 *and* 5 *are copied from Tycho's book,* Astronomiae Instauratae Mechanica (1598).

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Ptolemaic and Copernican views of the universe—and it is possible that he thought more highly of his own solution of this problem than of any of his other achievements. This was a rather strange compromise between the two alternatives: the planets, excluding the earth, travelled round the sun in Copernican fashion, but the whole system, thus formed, itself moved round the stationary earth. So far as the solar system is concerned this is mathematically equivalent to the Copernican conception, but it fails to account for the aberration of light and the annual parallax of the stars. These phenomena, however, were not known to Tycho, and he accordingly believed that he had found the true answer to the central problem of astronomy; his last request to Kepler, in fact, was that he would interpret the observations according to the Tychonic and not the Copernican system. This is by no means a unique example of a creator proving himself an indifferent critic of his own achievements.

The great work at Uraniborg came to a melancholy end in 1597. On the death of King Frederick in 1588 his son Christian, then only 11 years of age, came largely under the control of certain nobles, some of whom were inimical to Tycho. This circumstance—together, it must be admitted, with Tycho's somewhat arbitrary behaviour—led to an increasing degree of estrangement, which culminated in Tycho's position at Hveen finally becoming untenable. In March or April 1597 he left his historic observatory for ever. The instruments were gradually dismantled and some of them sent to him in Bohemia, but their great work was done. They were all too jealously guarded after Tycho's death by Curtius, who would not allow even Kepler to use them, and ultimately all were destroyed by war or by fire. Of Uraniborg scarcely a trace remains. When Gassendi in 1647 visited Hveen in search of memorials of Tycho his findings were summed up in the simple phrase: 'There is in the island a field where Uraniborg was.'

On leaving Hveen Tycho, after some wandering, sought and obtained the patronage of the Emperor Rudolph. He was granted the Castle of Benatky, on the river Yser, about twenty-two miles north-east of Prague, and here, with reduced equipment, he resumed his observations. Little time was left, however, and the work in Bohemia is chiefly notable for the collaboration of Tycho and Kepler which produced such momentous results. Tycho's health gradually failed, and he died on 24th October, 1601.

As a man Tycho was not altogether lovable or admirable. He was overbearing, and failed to carry out the extremely light obligations which the generosity of the King had placed on him in return for his privileges. Of his utterly selfless devotion to astronomy, however, there is no doubt, and it must be recorded in his favour that in an unfortunate dispute with Kepler, in general a far more noble-minded man, it is Tycho who appears in the more favourable light. Also, while at Hveen it was his habit to give away medicines which, through his lifelong love of alchemy, he made a practice of preparing and in which he placed considerable trust. Tycho was fond of mystery and display, and his observatory at Uraniborg abounded in mechanical devices and imperceptible means of communication with which he liked to mystify his visitors. He wrote tolerable verses, some of which, as well as paintings, adorned the walls of his observatory. A typical example of the ornate character of the building was the ceiling and walls of the study at Stierneborg, which showed the Tychonic system of the world and the portraits of eight astronomers, ending with Tycho and 'Tychonides,' a successor yet unborn. In the inscriptions underneath, Tycho leaves his own work to the judgment of posterity, but the hope is expressed that Tychonides might be worthy of his great ancestor. Attached to the observatory was a dwarf called Jep, whom Tycho used to feed with an occasional morsel at table, like a dog. Jep was supposed to be clairvoyant and to have made some remarkable prophecies. Tycho was a firm believer in astrology and gave as rational a defence of the doctrine as was perhaps possible. In this, however, he was by no means abnormal, since astrology was a respectable university subject in his day, and only very exceptional men like Copernicus seem to have ignored it; open disbelief was almost out of the question. In short, Tycho was a typical child of the Renaissance—one of those strange mixtures of the medieval and the modern which are so baffling to us today.

Enough has been said, however, to indicate the indispensable part which Tycho's work played in the development of astronomy. In a sense he was more of an originator than most of the deeper thinkers of his time, for while the perception of the necessity for accurate and systematic observation called for a less powerful intellect than the rational organization of the universe, it was much less conformable with the spirit of the time.

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The measurement of coloured light

JOHN W. T. WALSH

The comparison of light intensities when the sources are of the same colour is susceptible of high accuracy, but for experimental and commercial purposes it is often necessary to compare sources which differ widely in colour. The problem then becomes much more difficult owing to differences in the reaction of observers, particularly when the light is dim. In this article the accuracy and limitations of modern methods of colour photometry are surveyed.

The measurement of light is usually carried out by means of a photometer, in which two illuminated white surfaces are compared by an observer, who adjusts the illumination of one or both until he judges that they are equally bright. Any marked difference of colour between the lights illuminating the two surfaces makes this judgment more difficult and uncertain; nevertheless the observer can always find a condition such that surface *A* is undoubtedly brighter than surface *B* and another in which *B* is certainly brighter than *A*. The methods used in heterochromatic photometry have been devised with the object of reducing as far as possible the gap between these two conditions. The fact that this gap need not exceed two or three parts in a thousand when there is no colour difference gives some indication of the target.

Unfortunately, in addition to the uncertainty which a colour difference produces in a single observer's judgment, there may also be a not inconsiderable spread in the results obtained by different observers. This results from the variations which are known to exist in the colour response even of normal-sighted individuals. For instance, the two coloured surfaces shown in figure 1 may be judged equal in brightness by one observer with normal vision, whereas another may well require the brightness of one or other surface to be increased by as much as 30 per cent. before he will assess them as equal.

In order that measurements of lights of different colours may be consistent, it has been agreed internationally that the methods used in heterochromatic photometry shall, in addition to reducing the uncertainty of a measurement, also make it agree with the results which would be obtained by an observer having a certain specified 'average' response to colour.

THE FLICKER PHOTOMETER

In the ordinary photometer-head, used when colour differences are negligible or at any rate quite small, the two surfaces are seen side by side. When there is a marked colour difference, however, an entirely different method of making the comparison is frequently employed. The two surfaces are rapidly alternated before the observer's eye so that he sees first one and then the other, and as the speed is raised the field of view presents a flickering appearance. The flicker diminishes and finally disappears altogether as the rate of alternation of the surfaces is increased. This rate is under the observer's control, and he is required to adjust the illumination of one or both of the surfaces until the speed at which flicker just disappears is a minimum. If there is no colour difference between the lights, the minimum rate at which flicker disappears is comparatively low, namely about ten to fifteen alternations per second. A colour difference, however, causes perceptible flicker at this and at considerably higher rates, depending on the extent and nature of the difference. The minimum for the particular difference present is found by trial and error, and observations are then made with the photometer set at this rate or something very slightly in excess of it.

It has been found that with this form of photometer the results obtained by different observers are relatively precise and consistent, provided certain conditions are fulfilled as regards the size and brightness of the field of view and the provision of a steady background of about the same brightness. Even under the best conditions, however, different observers do not obtain quite the same results when the colour difference is large, and it is then necessary to select observers whose colour response is close to that of the agreed 'standard' observer. For this purpose, each potential observer makes a measurement of two sources with a certain definite colour difference. These are obtained by the use of two liquids, one yellow

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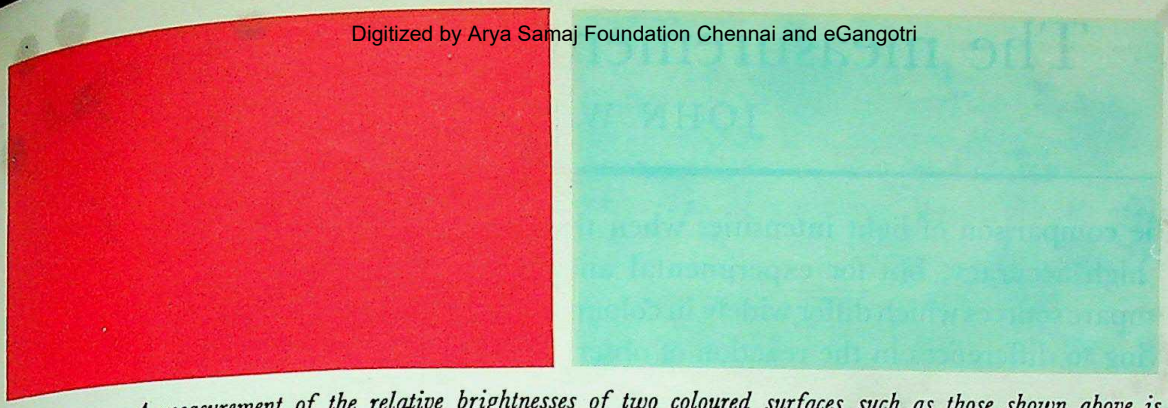

FIGURE 1 – *A measurement of the relative brightnesses of two coloured surfaces such as those shown above is subject to large uncertainties even for observers with normal colour vision.*

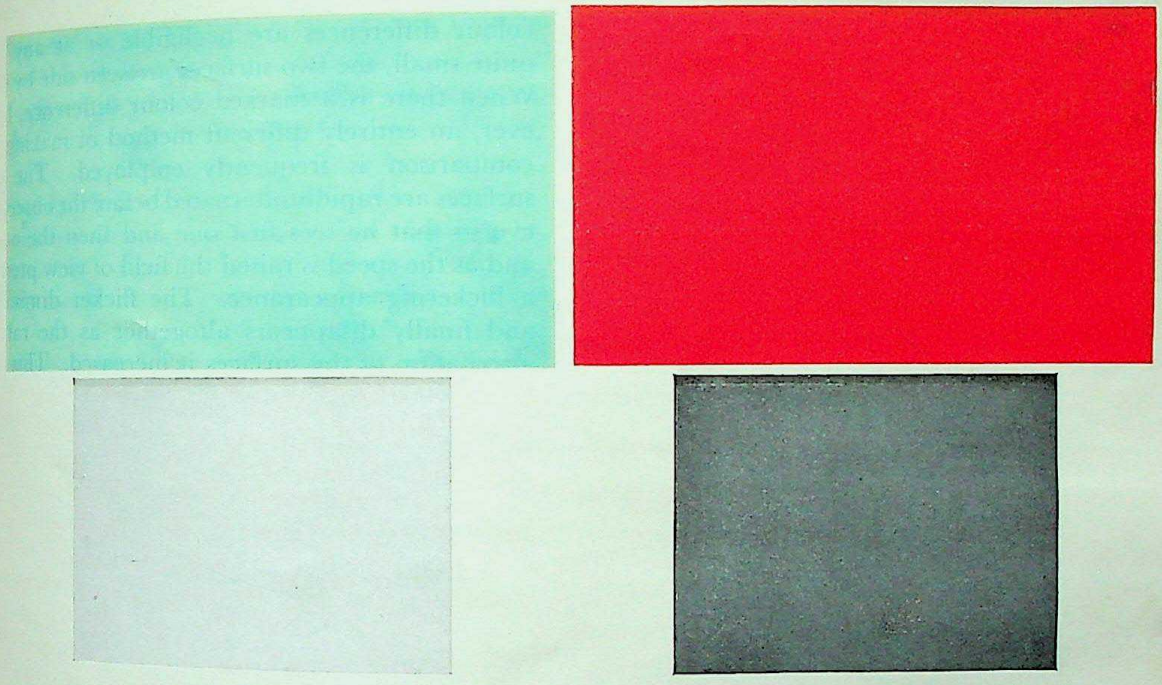

FIGURE 2 – *The grey patches show the relative brightnesses at very low illuminations of two lights, one green and one red, which appear equal at ordinary illumination values.*

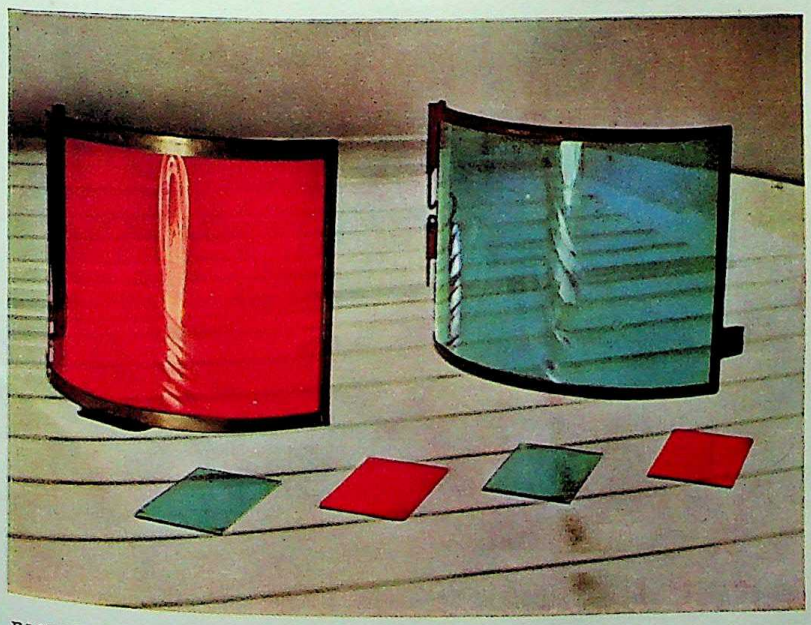

FIGURE 3 – *The coloured slides used in ships' navigation lights and the limit glasses used in testing them.*

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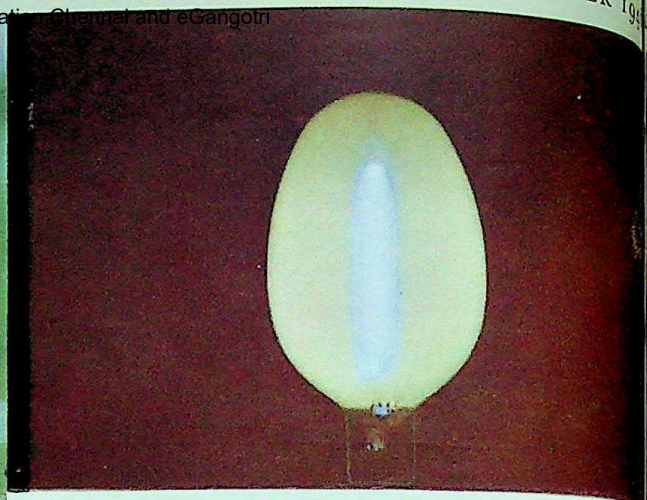

FIGURE 4a (*above and left*) – *The high-pressure mercury fluorescent lamp and some coloured objects illuminated by it.*

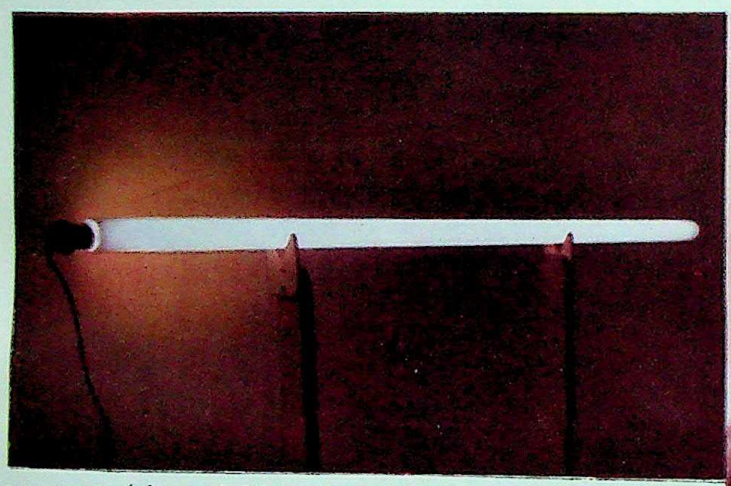

FIGURE 4c (*above and right*) – *The daylight fluorescent tubular lamp and the same coloured objects illuminated by it.*

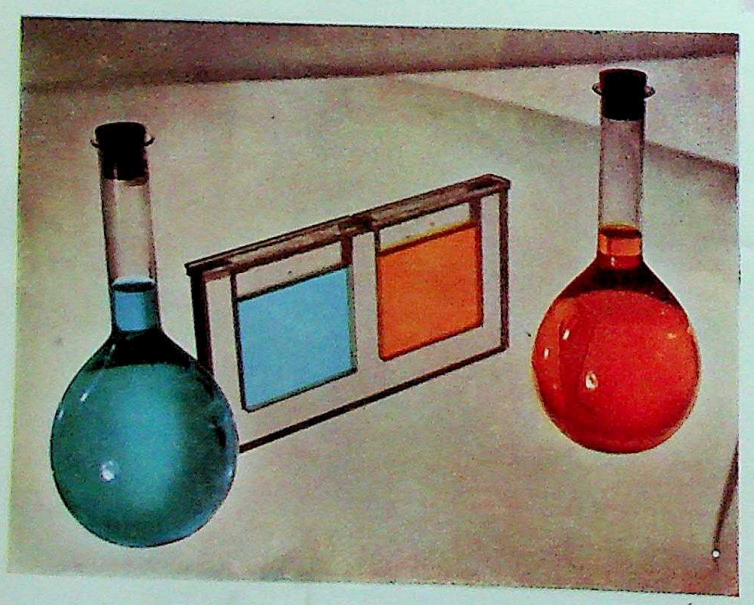

FIGURE 5 – *The blue and yellow solutions used for testing an observer's suitability for making measurements of coloured lights.*

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FIGURE 4b (above and right) – *The sodium lamp and the same coloured objects illuminated by it.*

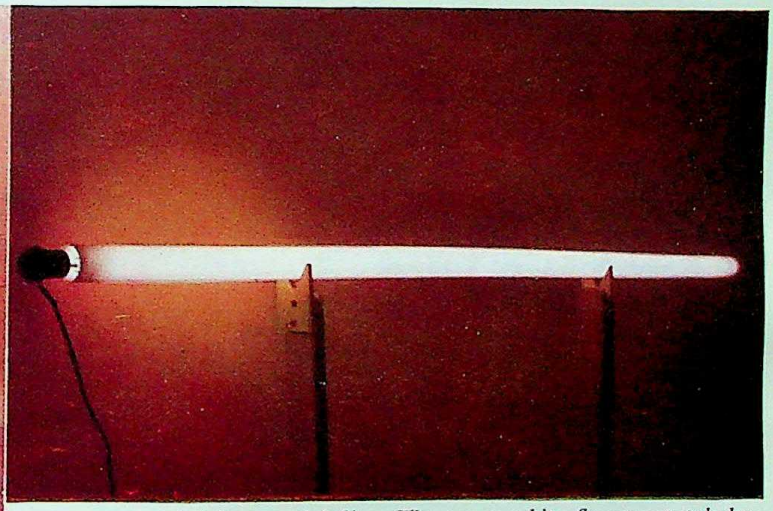

FIGURE 4d (above and left) – *The warm-white fluorescent tubular lamp and the same coloured objects illuminated by it.*

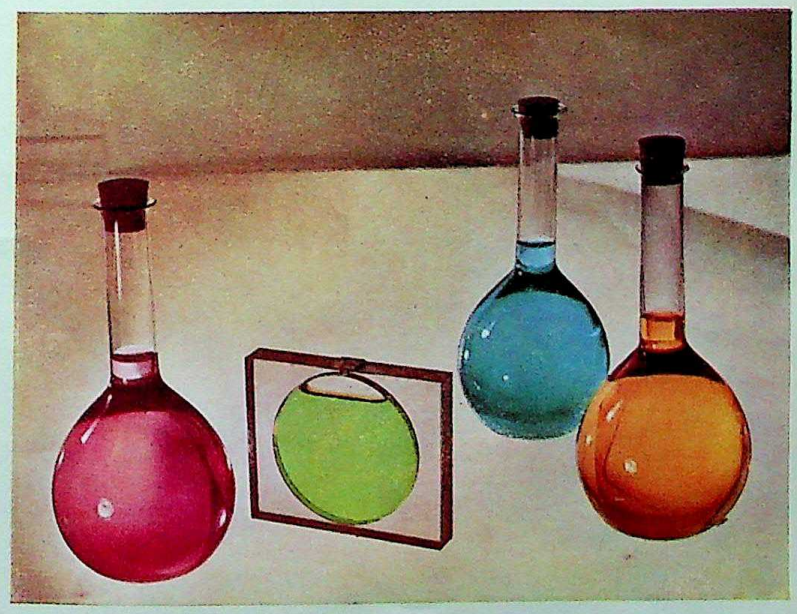

FIGURE 6 – *The liquid colour filter (and the component solutions) used in combination with a rectifier photocell to give a colour response similar to that of the average eye.*

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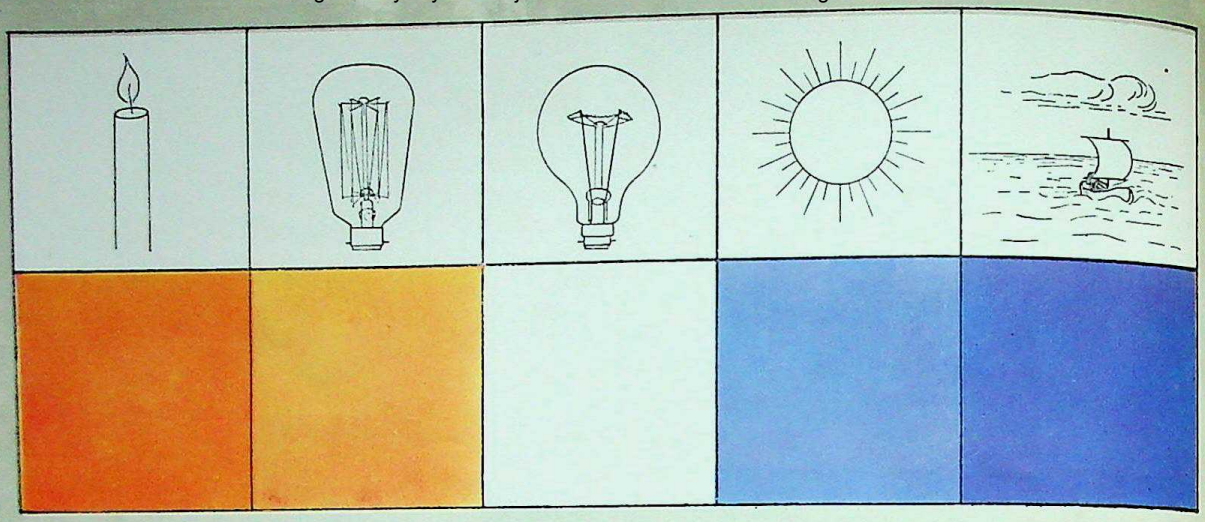

FIGURE 7 (*above*) – *The square patches show the colours of the light given by different familiar illuminants, viz. the candle, a tungsten-filament vacuum lamp, a gas-filled lamp, the sun, a blue sky. (The patches should be viewed by the light from a gas-filled lamp.)*

FIGURE 8 (*right*) – *Colour filters used in measuring sources of light of different colours.*

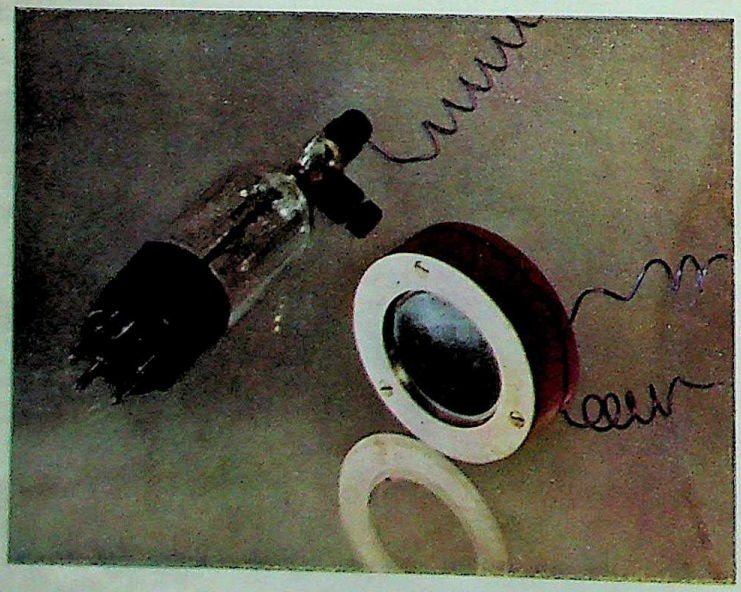

FIGURE 9 (*left*) – *Photo-electric cells used for light measurement. On the left a photo-emissive cell; on the right a photo-voltaic or rectifier cell.*

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and one blue, of specified composition and thickness. The double glass cell containing the two solutions is shown in figure 5. The ideal observer, using a flicker photometer, will find that these solutions transmit the same fraction of the light given by a lamp under-run to match a carbon-filament lamp. An observer whose results depart from this condition by not more than about 5 per cent. may be regarded as having a satisfactory colour response for ordinary heterochromatic measurements.

COLOUR-CORRECTING FILTERS

Instead of using a flicker photometer it is sometimes more convenient to remove the colour difference, either completely or to a large extent, by means of a coloured glass or a liquid solution inserted in the path of one of the lights being compared. Naturally, the fraction of the light which gets through the coloured medium must be known. Generally it is calculated from a curve showing the percentage transmitted at every wavelength throughout the visible spectrum.

This method is used for the photometry of tungsten-filament lamps or other sources in which light is produced by raising the temperature of a solid body, such as carbon or a metal filament, to incandescence. It can also be used for measuring daylight or sunlight. Figure 7, viewed by the light from an ordinary tungsten gas-filled lamp, shows approximately the colour of the light emitted by such sources.

The correcting filters are, of course, similar in colour, and specimens of the actual filters employed are shown in figure 8.

GAS-DISCHARGE AND FLUORESCENT LAMPS

The recent introduction of gas-discharge lamps, in which the light is produced by an electric discharge passing through mercury or sodium vapour, has brought into great prominence the difficulty of measuring light having a very marked colour. Typical lamps of this type are shown in figures 4*a*, *b*. A still more recent development is the fluorescent lamp, in which the colour of the light from the mercury discharge is changed by means of a coating of fluorescent powder on the walls of the glass tube in which the discharge takes place. Two such lamps are in common use. In one the colour of the light approximates to daylight; in the other it is a 'warm' white.

The colours of the light given by these four types of lamp are shown in figure 4. Each of the four pairs of pictures shows, side by side, (*i*) one of the lamps mentioned and (*ii*) the appearance of a group of flowers, etc., when seen by the light from a lamp of this type. The light from such lamps is measured either by means of the flicker photometer or by using colour filters specially designed to give a match with the coloured light when placed in front of a tungsten-filament lamp.

PHYSICAL PHOTOMETRY

For many types of photometric measurement it is possible to use a photo-electric cell in place of the eye. Such cells are of two types, and a specimen of each is shown in figure 9. The cell on the left is of the 'photo-emissive' type, in which the light to be measured falls on a sensitive metal surface contained within a glass bulb which is either evacuated or contains an inert gas at low pressure. The bulb contains also a wire mesh, and this is connected to the positive pole of a battery, the sensitive surface being connected to the negative pole. The voltage between the sensitive surface and the wire mesh is of the order of 50 volts. When light falls on the cell a small current flows in the circuit, owing to the emission of electrons from the sensitive surface brought about by the light falling on it. Under carefully controlled conditions this current is proportional to the light falling on the sensitive surface, so that the device can be used for light measurement.

The other type of photo-electric cell, shown on the right in figure 9, is quite different in principle and is known as a 'photo-voltaic,' or sometimes as a 'rectifier,' cell. It consists of an iron plate covered with a layer of a semi-conducting material (usually selenium), which in turn is covered with an exceedingly thin layer of a metal such as gold or platinum. When light falls on this layer, a portion of it penetrates to the selenium, and if the layer and the iron plate are connected through a sensitive electrical measuring instrument a very small current will be seen to flow in the circuit. Again, under proper conditions, this current is proportional to the light falling on the cell. Advantages of this type of cell are its portability and the fact that it needs no auxiliary battery, the current being generated by actual conversion of the light energy.

As might be expected, no cell shows a colour response which is the same as that of the standard 'average' eye, and while this is immaterial so long as there is no difference in the colour of the lights being compared, it naturally introduces large errors when coloured light sources are being

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measured. The difficulty is again overcome by the use of colour filters. In this case, to put the requirements in general terms, the filter must transmit well for a colour to which the cell is less sensitive than the eye and badly for a colour to which the cell is oversensitive. Although one cell differs from another in colour response, nevertheless the variation among cells of the same type is fairly small, and it is therefore possible to show a typical correction filter in figure 6. The liquid in the final filter is of a greenish colour, and is made up of three simple components shown separately in the three flasks.

MEASUREMENTS WHEN THE LIGHT IS DIM

The colour response of the eye remains constant so long as the brightness of the surface viewed is not reduced below that usual in a well-lighted room. For a much lower brightness, however, such as that of a surface seen by moonlight, the colour response alters very markedly. At such levels the eye's sensitivity to blue and green light, compared with its sensitivity to red light, is very much greater than at normal brightness levels.

The magnitude of this effect is illustrated in figure 2. To anyone with normal colour vision, the red and the blue patches appear approximately equal in brightness when seen by day. At a very low level of illumination, however, their relative brightness will appear more or less as shown by the two grey patches printed beneath them. Another illustration is provided by the appearance of a pathway illuminated solely by traffic lights at night. These lights are about equal in intensity, yet the pathway appears much brighter under the green light than it does under the red.

It will be clear, therefore, that the measurement of coloured light must always be carried out at a sufficiently high brightness.

SPECIAL PROBLEMS

As an example of a different type of measurement in which large colour differences are encountered, the control of the coloured glass slides used for ships' navigation lights may be mentioned. Two such slides are shown in figure 3. It is necessary that these glasses should be neither too dense nor too light and the control applied is to compare them with pairs of 'limit' glasses, one of each pair having the highest and the other the lowest permissible transmission. The limit-glasses used for the purpose are also shown in the figure.

Another example is the measurement of the brightness of the luminous markings on aircraft instrument dials. Some of these are of a radioactive luminescent material, like that used for the ordinary luminous watch, and the colour is a bluish green. Others are non-luminous in the dark but when illuminated by ultra-violet light glow with an orange-red colour. The brightness is measured by comparing the dial under test with a stencil of the same pattern which is placed in front of a sheet of opal glass or other translucent material. This is illuminated from behind by a lamp, the candle-power of which can be varied at will by the observer. A filter is used in front of the lamp to give a colour match with the dial, and the candle-power of the lamp is adjusted until the dial and the stencil appear to have the same brightness. The stencil can then be removed and the brightness of the translucent window measured by means of a suitable type of photometer. The effect of the filter can be allowed for in one of two ways. Either the brightness of the translucent window can be measured with the filter removed, the results being then multiplied by the transmission factor of the filter, or a second similar filter can be inserted in the photometer so that there is no colour difference when the brightness measurement is made. In this case the transmission factor of the filter is allowed for in the calibration of the photometer. This particular problem in heterochromatic photometry is often complicated by the fact that the brightnesses used are in the region where the visual phenomenon mentioned in the last section has to be taken into account.

CONCLUSION

It will be clear from all that has been said above that the measurement of coloured light is beset with many possible sources of error, so that the results can never be as accurate as those in which no colour difference is involved. Nevertheless by the adoption of the methods described, an accuracy sufficient for most commercial purposes can be obtained.

It is interesting to note that the difficulty was recognized by the earliest workers in this field of measurement, for Bouguer, who has been called the 'father of photometry,' describes as 'embarrassante' the comparison of two lights of different colours, and Lambert, writing in 1760, says 'Aegre comparantur claritates, quae colore plus minusve differunt.'

The author wishes to express his thanks to his colleague, Mr J. S. Preston, and to Mr E. B. Sawyer, Director of the E.L.M.A. Lighting Service Bureau, for their help with the illustrations.

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The museum as an aid to popular science

F. S. WALLIS

The educational and cultural value of museums is frequently underestimated through failure to recognize how greatly museums of today differ from those of even a few years ago. Dr Wallis here describes the kinds of scientific work museums are now undertaking, and makes a number of constructive suggestions for their future development. Himself the director of a large city museum, he realizes the handicaps that museums still suffer, but his vision of the possibilities is invigorating and should be of particular interest to scientists.

The term 'museum' has for many years conjured up visions of dust, dirt, and endless rows of specimens, arranged with a soulless, meticulous care. It is thus difficult for many to realize how great a revolution has taken place, making the museums of their maturer years far different from those associated with their childhood. The name remains unaltered, but the ideas and aims of present-day curators are far removed from those of their predecessors of even fifteen or twenty years ago.

Museums originated as the systematic and public expression of man's inherent tendency to collect and conserve. As might be surmised, objects of natural history and ethnological interest were the first to attract him, and vast and unwieldy collections of these materials were the result. Those in charge were concerned firstly with the acquisition and preservation of the material entrusted to their charge, and secondly with its systematic arrangement. This latter function was carried out in a strictly scientific manner according to the latest classification available. Serried rows of objects resulted, and with little attempt to make the display attractive it is small wonder that museums lacked inspiration and vitality. They made little appeal to that final arbiter, the general public, and consequently lacked funds and adequate man-power. Notwithstanding such adverse factors, museums achieved much, for their first great task was to collect, describe, and exhibit the contents of the world. The Linnean system provided the basis for this mighty inventory as far as natural history was concerned, and various other classifications were used in anthropology and archaeology. That the task was well done is evidenced by the mass of descriptive literature which resulted, much of which was compiled, directly or indirectly, by members of the curatorial profession.

It might perhaps be interpolated here that recent practice has tended to separate the work and activities of museums and art galleries. There is a growing consensus of opinion that, in the larger centres of population at least, such a course is desirable, though it is also stressed that the buildings in which the museum and art gallery are housed should be adjacent. This article deals exclusively with museums.

Museums provide for the *whole* public and are visited for many different reasons. Firstly, there are the 'umbrella' folk who enter to escape a passing shower, though even in that transient state they should be catered for by some arresting exhibit; secondly, intelligent and interested laymen, members of local cultural societies and students who wish to know more about their own particular branch of knowledge; and thirdly, those who are capable and desirous of conducting research in their own well-defined fields. In any discussion on the relationships of science and the museum these three types of individual should be kept in mind.

Those responsible for the policy of museums at the present time are increasingly conscious of the fact that to the functions of collection and conservation must be added that of pleasurable instruction. The material must be interpreted to the public, and the vast stores, accumulated in some instances throughout a period of over a hundred years, must be turned to the educational and recreational advantage of the community. The recent Education Act makes it quite clear that in Britain opportunity will be given to all to develop whatever talents they may possess, and to learn more about their fellow men and environment. This is a wonderful opportunity for museums to make science, in its broadest conception, known to the public. Alone amongst public services the museum makes use of the three-dimensional, visual method of education. The basis of the craft of a museum curator is that he enables people actually to see the object rather

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than to read or hear descriptive phrases concerning it. An object in a museum, accompanied by well-chosen, related material and provided with carefully written labels, is a powerful though silent source of instruction. With these factors in mind, we can now discuss how museums may develop in the future as an aid to science and as a help towards bridging the gap between the scientist and the layman—a gap which increased specialization tends to widen.

In the first place, museums can use their present material to illustrate and interpret the more traditional sciences—botany, geology, zoology—according to modern ideas. They can, for instance, show that ecology may be much more interesting than taxonomy. This indeed is a natural development of the previous period in the history of museums devoted to collection and description. The entrance hall or vestibule of the museum could be used for a large diorama portraying a typical glimpse of local scenery complete with the associated plants and animals. In such a display it might be possible to use carefully selected masses of the local rock, together with plants, shown either as life-like models, or by carefully preserved natural specimens, and typical animals set in characteristic attitudes. A scene (figure 1) typical of the Gower Coast and shown at the National Museum of Wales is an excellent example of this method of presentation. In some regions one such exhibit might be sufficient; in other more fortunate areas where several completely different types of scenery occur, more than one diorama would be needed. The scenic and ecological displays could be supplemented by realistic groups portraying local civilization in the prehistoric and historic periods, as far as these come within the policy of the museum. Such 'entrance hall' exhibits, adequately lighted by modern fluorescent tubes, would prove arresting to the 'umbrella' type of visitor. If the storm were of sufficient duration he might carry away a permanent impression of principles underlying the formation of the scenic beauty and the associated plant and animal life of at least one portion of his environment.

Although such exhibits would be of interest to the more serious layman, his requirements are more detailed, and for him a series of galleries portraying the principles of the sciences of geology, zoology, botany, and archaeology is necessary. By means of a simplified planetarium, or perhaps an orrery, the visitor is led to contemplate the earth as part of the solar system. The immense distances involved and the relative sizes of the sun, earth, and other planets can be shown graphically, and the visitor is then naturally drawn on to a study of the earth itself. Here the broad principles of rock formation, folding (figure 5), and destruction, can be shown, and the forms of early life illustrated by well-chosen, preferably local, examples.

The visitor might now be led—one-way traffic should always be planned in museums, even if the more impatient continually short-circuit the route—to the always popular zoological department. Here again the aim should be not so much to provide a correctly named example of each animal in the region, or—if means parallel ambition—perhaps in the world, but to display such material as shall draw attention to basic principles and relationships and to typical examples of the various phyla. As with the other traditional museum subjects, the application of zoology to everyday life is the important aspect to be stressed. This is particularly well illustrated in an exhibit at the National Museum of Wales, which deals with the animal life of a town and the alterations which might be effected in it by modern planning.

Again, in botany, the temptation to provide a faultless but monotonous record of the flora of the area must be avoided, and natural associations, together with ideas concerning plants as living organisms in a definite environment, should be emphasized. A stand exhibiting wild or cultivated plants of the region with another for experiments with living plants is an essential and ever-popular display. Agriculture, horticulture, and forestry offer a wealth of ideas for exhibits of this type. It cannot be too strongly stressed that the museum of the future will be concerned more with ideas than with objects. Galleries illustrating themes such as evolution, heredity, man's conquest of material, or transport through the ages (figure 4), will replace systematic and uninspiring series of stuffed animals, dried plants, and minerals.

With such a background of ideas connected with environment, the visitor naturally passes to a study of man and his works. This is a vast subject, and the available material is increasing daily. This section naturally commences with a study of man himself: the success of the Newark Museum in this direction is outstanding (figure 2). Most museums possess objects from the prehistoric and early historic periods of their own areas, often together with a superabundance of ethnological material illustrating the arts and crafts of various native peoples. Such material lends itself to

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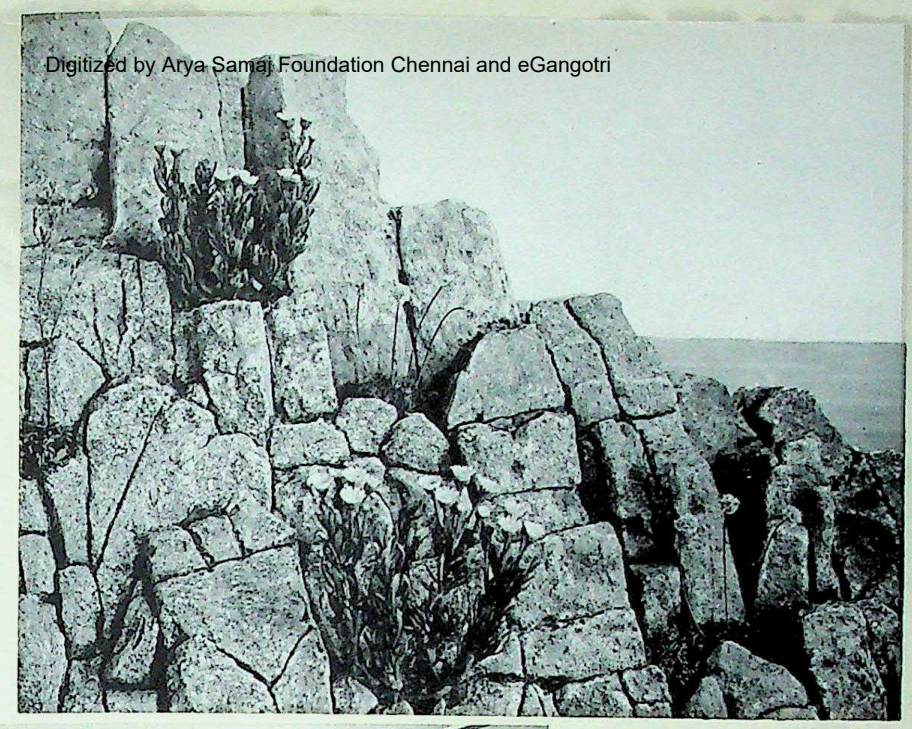

FIGURE 1 – *An exhibit in the Botanical Department of the National Museum of Wales, Cardiff, showing rock plants from the Gower Coast growing on limestone.*

(Courtesy of the National Museum of Wales.)

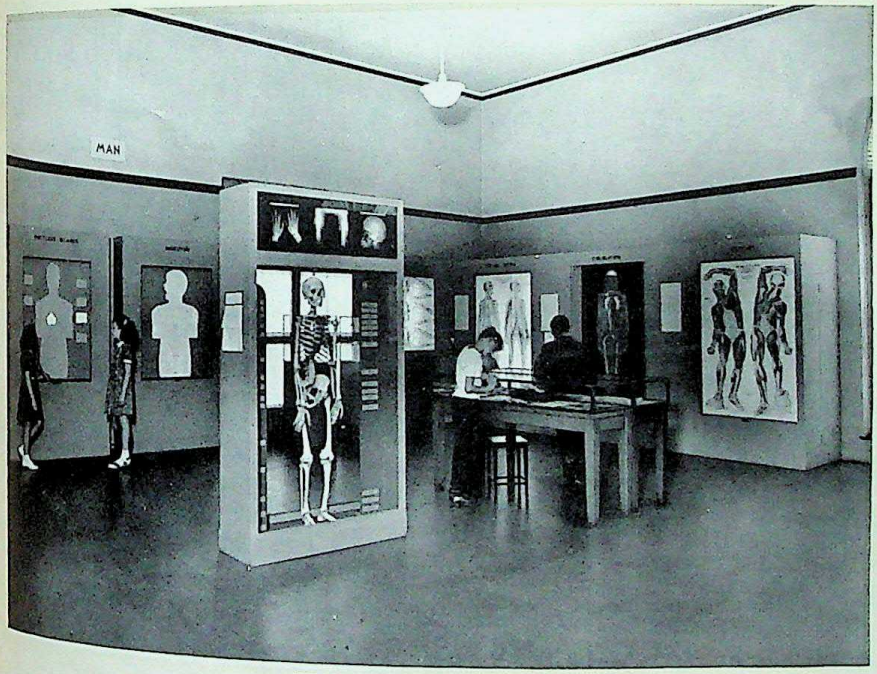

FIGURE 2 – *'Man' alcove. A striking exhibit arranged according to modern display methods and indicating the construction and working of the human body.*

(Courtesy of the Newark Museum, Newark, New Jersey.)

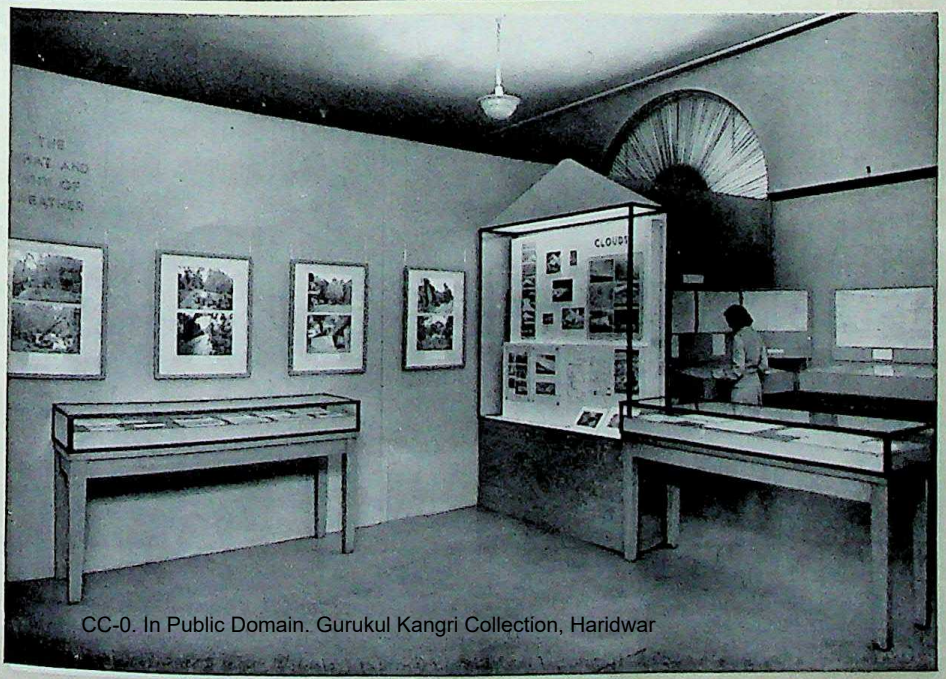

FIGURE 3 – *An exhibit to illustrate weather — generally regarded as a subject unsuitable for museum presentation. Newark Museum has prepared a successful exhibit by means of photographs and simple diagrams.*

(Courtesy of the Newark Museum, Newark, New Jersey.)

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FIGURE 4 – *Transport in the early nineteenth century. A diorama in the Children's Gallery, Science Museum, South Kensington.*
(*Courtesy of the Science Museum, South Kensington.*)

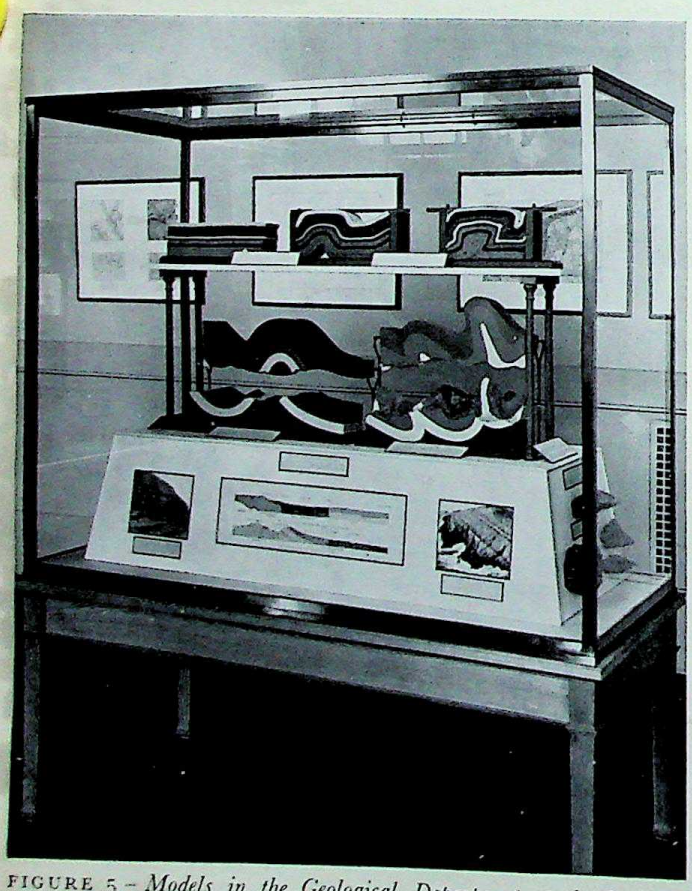

FIGURE 5 – *Models in the Geological Department at the National Museum of Wales, Cardiff, illustrating stratification and folding of rocks. Experience has shown that such an exhibit is understandable only without labels.*
(*Courtesy of the National Museum of Wales.*)

FIGURE 6 – '*New contacts change cultures*' *displays by modern technique the lines of change in varied types of artifacts—war clubs, pipes, and so forth—laid against four time zones.*
(*Photograph by Harvey Croze; courtesy of the Cranbrook Institute of Science.*)

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modern display methods, and the ingenious techniques which have been such a feature of the various war-time exhibitions sponsored by the Ministry of Information and other organizations will surely find their place in the museums of the post-war period. Indeed a striking exhibit at the Cranbrook Institute of Science, Michigan (figure 6), consisting of relatively few specimens arranged concentrically, indicates that such display methods have already been adopted. The tendency to show extensive typological series must be avoided, and the everyday life of the ordinary man and woman in the various historical periods —and, in a large museum, in various parts of the world—must be portrayed with all the vividness which curators can command. Recently, the immediate past has claimed the attention of museum committees, and the science of folk-life has been introduced. This deals with the crafts and industries of about the last three hundred years, and seeks to show how our forefathers lived and worked. It is a fascinating branch of science, still in the fact-collecting stage, though tentative and limited hypotheses are emerging. This branch of knowledge has a special value in that it invites the visitor to carry out simple observations for himself on intensely humanistic subjects, and it has inspired many a layman to collect facts in and about his own neighbourhood. To many, the museum clearly demonstrates that the first stage in any science is the collection of facts and evidence and not the formulation of a theory or hypothesis.

In addition to the entrance hall and the general exhibition galleries, there should be a series of rooms available only to the more serious student. These would contain the greater portion of the collections, arranged with careful precision and labelled according to the latest nomenclature available. This section provides the material for research—another important function in the policy of a progressive museum. The traditional museum subjects can thus be displayed more in accord with the results of modern science. Museums provide science with an effective and visual interpretation of its latest trends of thought, as well as with a mass of well-authenticated material for future research.

The interest of the general public in science, however, is swinging over to the astronomical, physico-chemical, medical, biological, and engineering aspects. Atomic structure is of greater present interest than butterflies and fossils. Although a few museums have displayed material and ideas illustrating some aspects of these sciences, it now appears certain that our institutions must seriously consider and meet this new demand, thus seizing their opportunity as the chief exponents of visual education.

Astronomy has already been mentioned as providing an introduction to the study of geology. But it can be treated in a far more detailed manner, and the recently increased popular interest in this science should be stimulated. In addition to the models already mentioned, the museum could exhibit other working models, with simple explanatory data, illustrating such matters as lunar and solar eclipses. The historical development of ideas concerning the birth of the earth is capable of demonstration, as are the astronomical uses of the telescope and spectroscope.

In illustrating chemical science in the museum, heed must be given to the *applications* of systematic knowledge, especially in local technical processes. The layman today wants to possess an increased understanding rather than to assimilate additional facts and curiosities of information unrelated to his individual problems. Although many local products are shown in the art gallery as works of art, it is in the province of the museum to demonstrate the technical processes involved in their production. New materials such as plastics, rayon, and the many other synthetic materials which have appeared in the last few years, can be exhibited and explained, with outlines of the methods used in their manufacture. A few simple experiments which could be set up and worked by the pressure of a button would be of value. Such exhibits will soon dispel the all too prevalent idea that it is only when articles and ideas are entirely out of date that they should be included in a museum. Museums can thus act to the public as the popular expositors of both the academic and the industrial chemist.

The ordinary man or woman is intensely interested in modern theories regarding the constitution of matter, as witness the extraordinary appeal of all literature relating to the atomic bomb. Much of this, together with the principles of X-ray analysis, is capable of visual illustration.

In many subjects, museums can provide the stable historical background which gives the basis for the solution of present day problems. This is especially true in physiology, anatomy, medicine, and even in psychology and sociology. Museums must show how the nation lives and works for its means of existence; how it deals with nature and its products. Exhibits illustrating the health and

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food of a nation, the many basic facts required for town and regional planning, and the technical processes involved in the preparation of new materials, are amongst those which indicate the new approach to subjects hitherto neglected. At the Newark Museum (figure 3), even a non-objective subject such as the weather has provided material for an exhibit.

Initiative is the essential factor for success in such museums of modern science. Diversity and not uniformity must be the keynote in museums as it is in the British nation. Museums today are in a state of transition from a well-established past, through a rather confused present, to a period of closer contact with the life of the community in the future. Science is daily achieving a greater mastery over matter in all its forms, and it is essential that museums should be to the fore in making this new knowledge available to the public, who must be, and indeed desire to be, kept informed of recent advances in science.

The new concept of museums as mouthpieces of modern science necessitates the close co-operation of scientific societies and specialists; it is only by their assistance and advice that museums can operate in these new fields of knowledge. Such relationships are of double benefit, for while museums inform the public of the progress of science and the work of scientists, they are also of service to scientific workers in their researches. Formal education is a process which is completed and not repeated, but true education, which is an awareness and appreciation of man and his environment, is never completed. It is the visual interpretation of this concept of education that lies within the province of museums to encourage and stimulate. By covering the whole field of science, museums can do much to enable individuals to discover and develop their particular interest in specific branches of the subjects.

Science, museums, and the interested layman form the three components of a system in which each is of service to, and mutually dependent on, the others. The interpretation of science is a formidable task and many expositors must be used. Not the least of these will be the objective value of a museum of science.

The author wishes to tender his grateful thanks to all those colleagues who in conversation or correspondence have discussed with him some of the matters in this paper.

Sir James Hopwood Jeans, O.M.

It is with deep regret that we record the death, on 16th September, of Sir James Hopwood Jeans, O.M., F.R.S., at the age of 69. Jeans was known throughout the world not only for his many original contributions to mathematical physics but also for his lucid expositions of science in books and articles intended for the general public. His academic career was a brilliant one, and among the positions he successively held were those of Professor of Applied Mathematics at Princeton (1905–9), Stokes Lecturer in Applied Mathematics at Cambridge (1910–12), and Professor of Astronomy in the Royal Institution. He held also many important offices and was at various times Secretary of the Royal Society (1919–29), President of the Royal Astronomical Society (1925–7), and President of the British Association for the Advancement of Science (1934). He was honoured by universities and societies throughout the world, and received, among other awards, the Royal Medal of the Royal Society, the Gold Medal of the Royal Astronomical Society, and the Franklin Medal of the Franklin Institute.

One of Jeans' first major contributions to science was his confirmation of Lord Rayleigh's law for black-body radiation. In this field he quickly recognized the significance of Planck's quantum theory and used it skilfully to develop his own theories. He gave too, in 1903, the first rigorous proof of Maxwell's law for the distribution of velocities among the molecules of a gas. Although his work materially advanced many branches of physics, Jeans is most generally known for his cosmogonic work. His brilliant theories of the origins of the planets and their satellites and of the source of stellar radiation have gained wide, if not universal, acceptance. He will be remembered too for his philosophical interpretation of modern science. Though his philosophical theories have excited much controversy, they represent a courageous and carefully considered attempt to answer problems whose manifest difficulties have deterred most of his contemporaries. His death is a severe loss to British science, the more so as it comes at a time when the rapid advancement of science is creating so many urgent philosophical problems. Jeans took a keen interest in ENDEAVOUR from its earliest days and was a valued contributor.

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The fluorescence of organic compounds

N. CAMPBELL

The study of inorganic fluorescent substances has led not only to results of value in the understanding of atomic structure but to the commercial development of the fluorescent lamp, described in the January issue of ENDEAVOUR. In the organic field too, fluorescence has proved of both theoretical and practical importance. Although the fundamental problem of the relationship between fluorescence and chemical constitution remains unsolved, its study has resulted in a wide knowledge of the facts relating to the phenomena.

'Nature is full of exquisite sights and sounds' wrote an English essayist, and of these 'exquisite sights' pride of place must surely be given to colour, whether it be in plants or in flowers, birds, or butterflies. Nor are the synthetic products of the chemist lacking in this respect: many and varied indeed are the colours to be found on laboratory shelves or in dyers' catalogues. Certain dyes are found to possess a characteristic brilliance known as *fluorescence*, the most familiar example of which is the vivid green shimmering colour obtained by adding the dyestuff fluorescein to an aqueous alkaline solution. Briefly defined, fluorescence is the property possessed by many substances of absorbing light of a certain wavelength and emitting part of it again as light of a greater wavelength.

Fluorescence was observed and recorded hundreds of years ago: Boyle, for instance, noted the colour of the extracts of certain woods. Later investigators, including the famous Scottish physicist, Sir David Brewster, joint founder of the British Association, studied the phenomenon, but though much of their experimental work was excellent, small progress was made on the theoretical side. It was not until 1852 that Sir George Stokes attacked the problem with systematic thoroughness, and gave a lucid account of the true nature of fluorescence.

FLUORESCENCE

To most of us, light means colour, so-called 'white' light being a mixture of the colours of the spectrum. Expressed in another way, white light is composed of light of different wavelengths. In the short-wave region appear violet and blue, and at the other end of the spectrum is red. Visible light, however, is only a limited range of light: adjacent to the ends of the visible spectrum are other forms, known respectively as *ultra-violet* and *infra-red* light. Though ultra-violet light, like other radiations such as wireless waves, is invisible to the human eye—it is sometimes known as 'black' or 'dark' light—its presence is easily detected in several ways. For instance, it darkens silver chloride and hence can be detected photographically. Its existence is shown more strikingly, however, by the colours, often of astonishing brilliance, which are produced when its invisible rays fall on certain minerals or chemicals. One of the best known of these is fluorspar (calcium fluoride), which fluoresces in ultra-violet light with a beautiful blue colour. Stokes, who observed this fact, invented the term fluorescence for this type of luminescence.

In the present article we shall confine ourselves for the most part to the fluorescence of organic compounds in ultra-violet light.

FLUORESCENCE OF ORGANIC COMPOUNDS

Ultra-violet light is most conveniently obtained from the mercury-vapour lamp, most of the visible rays being removed by means of a suitable glass filter. In this light it is probable that the majority of organic compounds fluoresce, but only in a small number of cases is the phenomenon easily observable. The following list (p. 156) gives some typical fluorescent organic compounds.

It is of interest that many compounds, such as quinine sulphate and anthracene, are colourless in ordinary light but may be detected and identified by their characteristic fluorescent colours in ultra-violet light. It must be remembered, however, that fluorescence may be, and often is, due to the presence of minute quantities of impurities. The classic example of this is found in the coal-tar hydrocarbon fluorene, which was first isolated by Marcellin Berthelot in 1867 during his famous researches on the pyrogenic hydrocarbons. Berthelot was so impressed by the fluorescence of this compound that he called it 'Fluorène.' Yet

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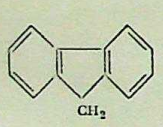
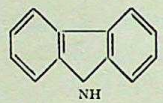
Organic Compounds fluorescent in Ultra-violet Light	
Benzene	*Feeble violet*
Stilbene	*Blue-violet*
Naphthalene (pure) ..	*Slight violet*
2 : 3-Dimethyl naphthalene	*Blue-violet*
2 : 7-Dimethyl naphthalene	*Feeble violet*
Anthracene (pure) ..	*Bright blue*
Anthracene (technical)	*Bright green-yellow*
Phenanthrene	*Violet*
Fluoranthene	*Brilliant green*
1 : 2-Benzanthracene ..	*Blue*
2 : 3-Benzanthracene ..	*Orange*
Pyrene	*Brilliant green-yellow*
Chrysene	*Bright violet*
Perylene	*Bright orange-red*
Carbazole (technical) ..	*Brilliant violet*
Carbazole (pure) ..	*Feeble violet*

fluorene when pure shows little or no fluorescence. A highly fluorescent commercial sample, for instance, when purified by chromatographic adsorption, gives a beautiful white but non-fluorescent substance.



Fluorene



Carbazole

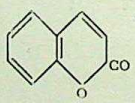
Carbazole, with a somewhat similar structure, is another compound generally regarded as fluorescent. Indeed, highly purified specimens have been authoritatively stated to possess bright fluorescence. We have found in our researches that synthesized carbazole has little or no fluorescence, and that chromatographic adsorption readily removes the fluorescent impurities from coal-tar carbazole.

Impurities influence the colour of fluorescence, and sometimes extinguish it completely. An illustration of the former effect is furnished by anthracene: this hydrocarbon when impure has a bright yellow fluorescence, but when pure it fluoresces blue.

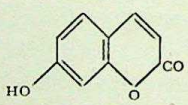
One of the most striking contributions of organic chemistry to medical science in recent years was Cook's isolation and identification of the carcinogenic compound in coal tar. The compound proved to be the aromatic hydrocarbon 3 : 4-benzpyrene, the isolation of which was made possible by its characteristic fluorescence. In vitamin research, another field intensively investigated, fluorescence has proved its worth. For example, vitamin A is readily detected by this means. A slice of tissue fixed in formaldehyde is illuminated with filtered ultra-violet light. If vitamin A_1 is present the specimen glows with a green fluorescence for a few seconds, while tissues with vitamin A_2 show a reddish glow. It is of interest that solid riboflavin gives a bright deep orange fluorescence, while in aqueous solution it gives a strong green one.

FLUORESCENCE AND CHEMICAL CONSTITUTION

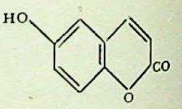
The organic chemist is never so happy as when engaged on that most elusive of problems—the correlation of physical properties and chemical constitution. Hundreds of papers have appeared in which colour and chemical constitution are discussed, and many workers have tried to correlate fluorescence and chemical structure, without, it must be admitted, much success. One or two useful empirical rules obtain. Bright fluorescence is observed mainly with polycyclic aromatic and heterocyclic compounds. This is evident from the above table and the coloured photographs. Fluorescence is also very dependent on the nature and position of substituents. For example, in alkaline solution coumarin does not fluoresce, while the 7-hydroxy derivative (umbelliferone) gives a beautiful blue fluorescence. The isomeric 6-hydroxycoumarin, on the other hand, does not fluoresce unless dissolved in sulphuric acid. No satisfactory explanation has been given for results such as these, and a general theory is still lacking in spite of the great number of available experimental data.



Coumarin



Umbelliferone



6-Hydroxycoumarin

FLUORESCEIN

Probably the best-known fluorescent compound is fluorescein, which can readily be detected by the naked eye in an alkaline solution even at a concentration no greater than 1 in 40,000,000. With the aid of instruments it can be 'spotted' at great dilutions—somewhere about 1 in 200,000,000. This powerful effect has been utilized in many ways. One application, of particular value during the late war, is in saving life at sea. Rafts, which are not easily seen from the air, have a tin attached containing a fluorescein derivative. When the raft

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FIGURE 1 (*right*)
Solid fluorescent compounds.
1. Anthracene (pure)
2. Anthracene (crude)
3. Benzpyrene
4. Phenanthrene
5. Pyrene
6. Fluoranthene

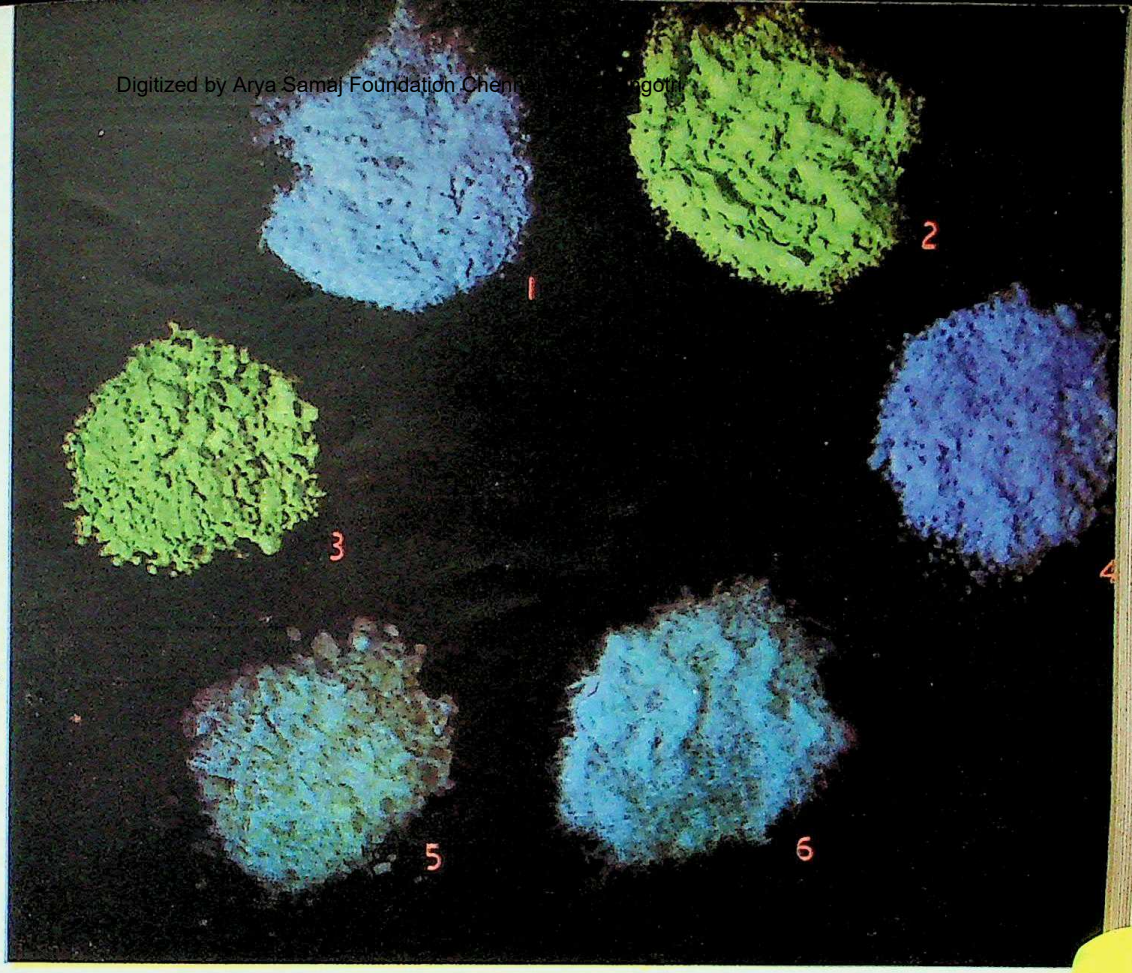
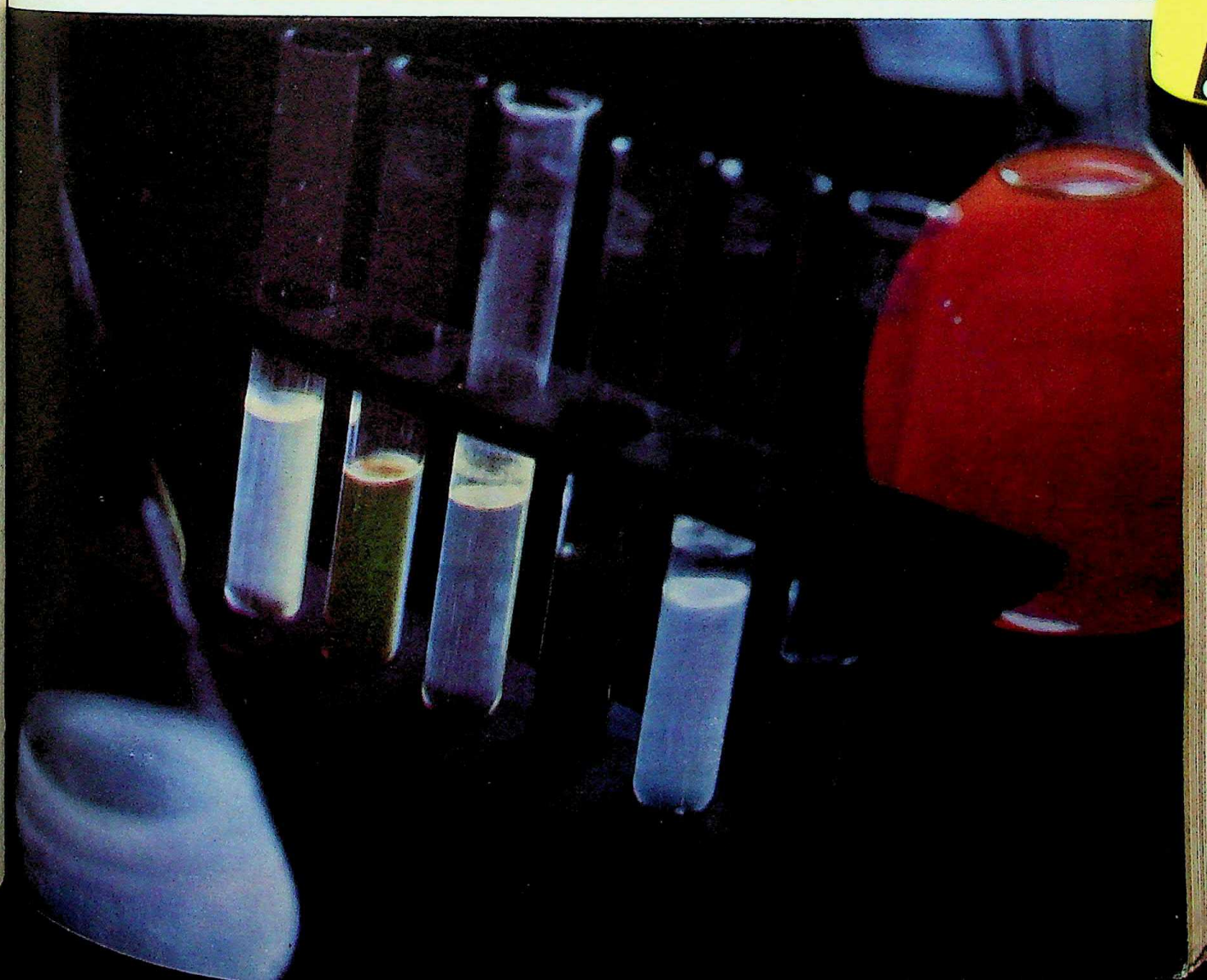


FIGURE 2 (*below*)
Fluorescent solutions.
(*Left to right*)
Coumaric acid (alkaline solution)
Quinine sulphate (water)
Perylene (ether)
Perylene (benzene)
Fluoranthene (benzene)
2:3-Benzanthracene (benzene)
Pyrene (benzene)
Phenanthrene (benzene)
Rhodamine B (glycerol-water)



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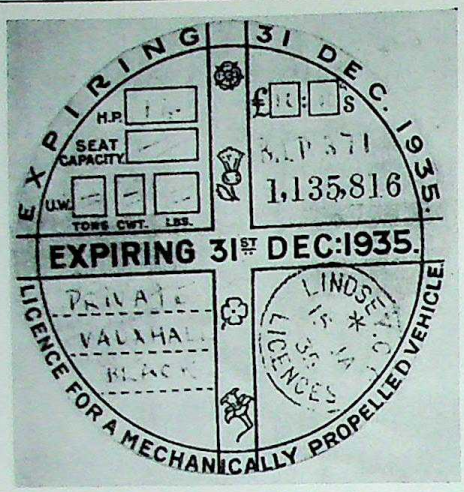

FIGURE 3a – *Photograph showing writing apparent to naked eye.*

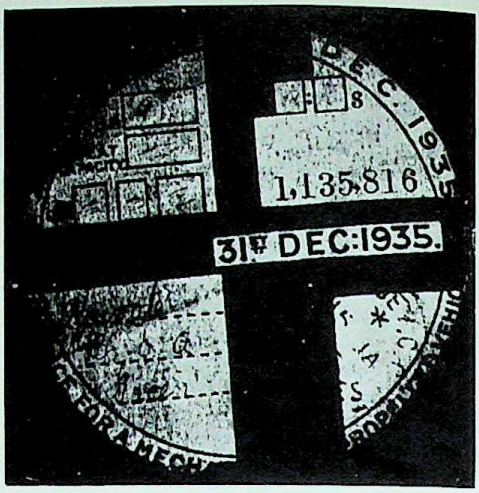

FIGURE 3b – *Photograph taken under ultra-violet rays from mercury vapour lamp, showing writing which had been erased by chemicals.*

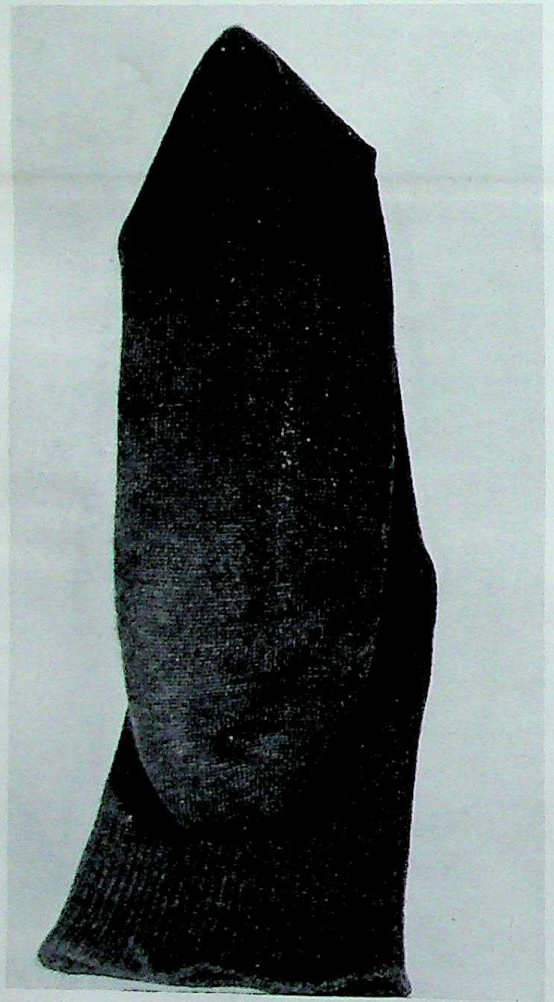

FIGURE 4a – *Sock photographed in ordinary light.*

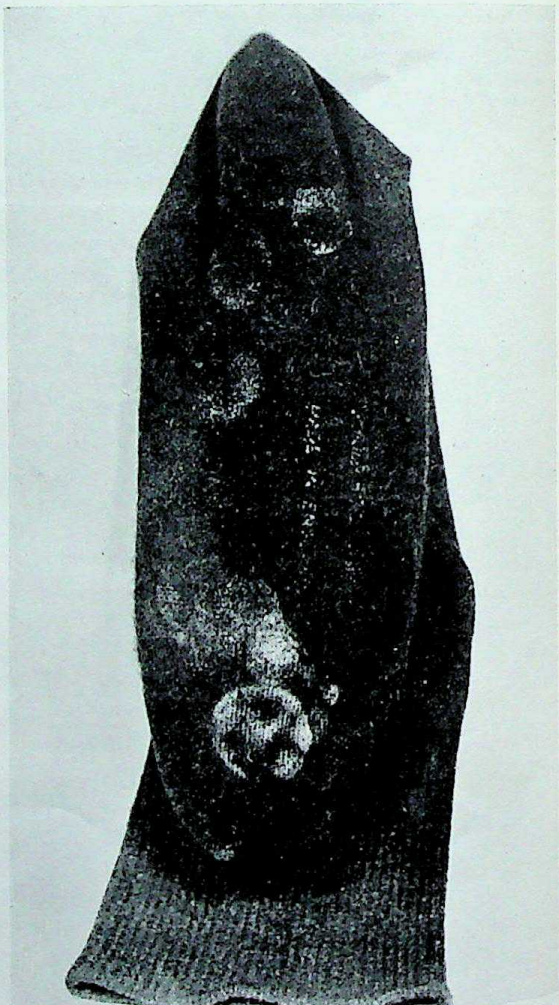

FIGURE 4b – *Sock photographed in ultra-violet light. The outlines left by coins are clearly seen.*

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comes in contact with the sea it is soon surrounded by a fluorescent surface of considerable size, thus assisting patrolling aircraft in their rescue work.

Fluorescein has been much used in water-supply investigations and hydro-geology. For instance, the drinking-water of a South African city some years ago was found to contain *B. coli*. By means of fluorescein a rock fissure was discovered through which poisonous swamp water was flowing into the city's water supply.

In a similar fashion, underground water connections have been traced and canal leakages detected. But by far the most dramatic and interesting application of fluorescein was made some years ago by Norbert Casteret, who described his results in a thrilling and fascinating book *Ten Years under the Earth*. Since 1787 there had been great controversy over the origin in the Pyrenees of the Garonne, the river upon which the inhabitants of the Upper Garonne (France) are dependent. It was held by many 'arm-chair' geographers that the Garonne rises at a large spring called the Goueil de Jouéou, situated in the mountains at an altitude of 4,580 ft. Casteret, however, as a result of three years' intensive exploration, came to the conclusion that the Goueil de Jouéou was fed from the Trou du Toro, a torrent high in the Pyrenees and some miles distant. This bold theory had been mooted before but never substantiated. Casteret settled the problem once and for all in 1931 by pouring 120 lb. of fluorescein into the Trou du Toro at 8 o'clock on a July evening. In a few seconds the torrent assumed the expected green fluorescence. The production of beautifully coloured cascades, however, was not Casteret's aim, and with his companions he hurried to the Goueil de Jouéou. At 6 o'clock next morning they observed with excited delight that it too exhibited the vivid green fluorescence —a delight not shared by the local inhabitants, who viewed the 'diabolical' colour with superstitious alarm.

Casteret's discovery was not only of academic interest but of great economic importance, as there was a proposal afoot to divert the waters of the Trou du Toro for power in Spain. Casteret's work resulted in the project being dropped: otherwise the waters of the Garonne would have been halved, with serious consequences to the Frenchmen whose livelihood depended on that river.

CRIMINOLOGICAL INVESTIGATIONS

Many objects which in ordinary light excite little or no notice fluoresce distinctively in ultra-violet light, and it is therefore not surprising that fluorescence has proved of great service in criminal investigations. 'Invisible' inks show up splendidly, and erasures by chemical means are instantly detected in this light. Again, many postage stamps are of particular value without their postmarks, and 'used' stamps are sometimes treated most skilfully by experts, so that careful examination reveals nothing irregular: yet such erasures are obvious under the lamp. Genuine pearls, too, can be distinguished from artificial ones, but not, of course, from the cultured variety. It may be noted in passing that fluorescence is no respecter of persons: in the revealing rays of the ultra-violet light, hair dyes fluoresce strongly, while it has led many a blonde to admit her debt to chemistry in general and hydrogen peroxide in particular.

Space forbids more than mere mention of one of the methods used by the police. Fluorescent powders have proved of great assistance, and the following two investigations by the City of Edinburgh police are given to illustrate this.

Money disappeared on several occasions from a locked cabinet, and suspicion fell on a certain man. A sum of money was placed in the cabinet, some of the coins being powdered with anthracene and the remainder with another fluorescent powder. The box was later opened and 17s. were found to be missing, whereupon the detective officers called at the house of the suspect, who raised no objection to being searched. No money was found in his possession, but in ultra-violet light tell-tale fluorescence was observed on his trousers outside his pocket. Confession, however, was obtained only when the right shoe and sock were examined under the ultra-violet lamp: distinct fluorescent patches were to be seen on the inside of the shoe, while on the sock the well-defined outline of several coins could be seen (figure 4*b*). The coins when recovered still fluoresced strongly.

Figure 3 shows clearly that a road licence found on a motor-car in Edinburgh and appearing to refer to a 14 h.p. private Vauxhall black motor car had been issued for a 9 h.p. private B.S.A. green motor-car. It was by this means that inquiries were started which led to the arrest of thieves who had stolen the licence in London and were using a car hired in that city. When arrested they had in their possession two bottles of liquid capable of rendering the handwriting on a car licence quite invisible in ordinary light.

NOTE: I have to thank Chief Constable Morren, of the City of Edinburgh Police Force, for his courtesy in supplying me with information and photographs.

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The values of science

E. F. CALDIN

Mr Caldin's article on the role of science in society, published in the April issue of ENDEAVOUR, aroused much interest. In this second article he discusses the relationship between science and the philosophical values of truth, goodness, and beauty. Such studies are of particular significance at the present time, when concentration upon the material aspects of science has created philosophical problems of international importance.

People associate two sets of values with science. One set is concerned with the advantages in material welfare that can be expected from technology based on science. The other is concerned with the values of science as such. It is with this second topic that I am to deal: the value to scientifically minded people of natural science and scientific life, considered in themselves and not as a means to improving material conditions.

I shall assume that we can assess the value of scientific knowledge by considering to what extent the picture of nature which it presents to us is characterized by truth, goodness, and beauty, and to what extent, further, this picture reveals to us the corresponding 'values' in material nature.[1] Truth is obviously connected with knowing, and goodness with loving; for brevity's sake we shall not delay longer on their definition. Beauty is closely connected with the other two values, and we may say that things are beautiful in so far as their truth and goodness lie open to our minds, so that we can grasp their forms intuitively. A friend is beautiful to us—more beautiful than a stone, say—because we have a certain intuitive knowledge of the character of the friend, and rejoice in it. We know a friend as a unity, a person, not as a series of episodes or actions; and by intuition, not by discursive reasoning. It is this intuitive knowledge of a lovable being which constitutes the perception of beauty. Thus beauty is one kind of good, arising from one kind of knowledge; and so it is intimately connected with goodness and truth. Further, it may be argued that truth, goodness, and beauty all depend on *form*—order, pattern, design, unity. A thing is both more knowable and more lovable the more developed is its form—a friend more than a squirrel, and a squirrel than a pebble. Now, it is in respect of form that these levels of existence—human, organic, inorganic—differ from one another. The material is the same for all—the same set of chemical elements, the same physicochemical laws—but the form of the man is a rational soul and so higher than that of the organism, which in turn is capable of growth, development, and reproduction, and so is higher than that of inorganic nature. And the higher form is at once more knowable and more lovable; and since it is more open to our intellectual grasp or intuition, and since when intuited it gives us the more delight, it is also the more beautiful. It is by degrees of form, then, that we can assess value.[2]

We can apply this treatment to beauty in art, and first to the 'fine arts.' These arts, I shall assume, are concerned with *significant* form: the artist must select and distil the data of experience so that the form he creates shall give an intuitive vision of some reality. What delights us at first sight in the work of art is the intuitive knowledge of its form. The prima facie beauty of a work of art is not the beauty of anything it represents; it has an independent beauty, related to the joy of seeing something as a whole, of reaching intuitive knowledge. If the reality of which the form is significant is beloved too, we are the more delighted, because of the further beauty that we reach through the work of art. We find a portrait as such beautiful because we see there condensed into one form the whole complex of a character, a human life; if the character is beloved too, we are the more delighted with this beauty revealed and intuited through art. A work of art, then—a significant form—opens to us both its own beauty and that of the reality it represents.

Evidently the greater the range and depth of the experience drawn upon, the greater will be

[1] For lack of space I have had to simplify very drastically the philosophical background here. I can only hope that the result is not misleading.

[2] Cf. J. Maritain, *Art and Scholasticism*, etc.; and various writers epitomised in E. F. Carritt's collection of texts, *Philosophies of Beauty*.

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the work of art. We all think the *Divine Comedy* a greater poem than some slight lyric which may nevertheless be as adequate to its tiny theme as Dante's poem is to its mighty one. The work of art is the greater, moreover, the more the outer form is adequate to the reality represented. In proportion to the reality represented, the form must have a unified complexity, an ordered richness, a variety in unity. Variety in unity, indeed, will be a clue that we can use in treating of beauty in philosophy, in literature, in science, in mathematics. It is not the whole of beauty, but in discussing the value of an intellectual structure it is the characteristic by which one may best assess beauty. A table of integrals, for instance, is less intelligible and less beautiful than an elegant mathematical theorem, because our minds can seize the theorem as a whole but not the collection of integrals, which has no logical unity. We assess value in terms of form, and form in terms of unified variety.

We can now turn to natural science, and to material nature which is the source of its data. The values of the two are distinct. We may think of science as analogous to a work of art, in that it has its own form, constructed to reveal or be significant of the form of nature (or rather its quantitative aspect). We can treat science as, in the first place, a systematization of sense-data, a unification of measured quantities.[1] Measurements are brought into rational relations with each other by constructing functional relations from them, and these empirical laws are related by more general laws. These laws again are unified by the theoretical interpretation, from which (if it were complete) the empirical laws could be deduced, and thence the behaviour of experimental systems. It is in this unity, this form, that we can find the beauty of science; this is the kind of harmony, of variety in unity, that characterizes it. It is a unity in which are combined measurements of diverse phenomena, empirical laws, and theoretical interpretations of all degrees of generality; all are unified in so far as they are deducible as particular cases from the general theoretical interpretation. The unity is not solely a matter of the logical rigour of the theoretical interpretation (analogous to the logical rigour of mathematics); it is a richer unity, because experimental observations on material systems are unified within the logical scheme, in so far as deductions from that scheme are in agreement with them. This is the version of variety-in-unity peculiar to natural science. It occupies rather a low place among the many types of intellectual beauty—compared with the beauty of great poetry, of music, of philosophy, it is low indeed—yet it is genuine beauty, and it has its own appeal.

We can, however, consider science as not merely a unified scheme, but as a source of rational beliefs about material nature. Since it exhibits a logical order, and since it is based on experience of material nature, it evidently presents to us some image of the order in nature; of the form of nature, the causal interdependence of things and events. But the scientific scheme with its merely logical order cannot be an adequate account of the order of nature, which must be causal and not logical. It appears that in science we symbolize the causal order in nature by the logical order of the theoretical scheme, i.e. we symbolize causality by deducibility. This is the way in which science is significant of nature.

We can see why it is that physical science must be content with thus reflecting, rather than describing, the form of nature, if we consider the method of science. In physical observation we limit ourselves in two ways. In the first place we confine ourselves to material nature; we omit all consideration of human acts—such as those of the human agent, the experimenter—and of the First Cause, God, who holds nature in being. In the second place we confine ourselves to the measurable aspects of a material object. We find that there are relations between the measured quantities (such as length and temperature) which can be expressed in the form of equations, and we construct from these equations a theoretical interpretation which unifies them. Obviously this theoretical scheme will be mathematical, since it has to bring unity into a set of equations; it will itself be a set of equations from which the experimental relations can be deduced. Consequently the scheme will admit only inferences and must neglect causes. And it is evident that the reason why the scheme is mathematical is that at the start we confined ourselves to measurable characteristics. Thus the limitations of the theoretical scheme, as a source of beliefs about nature, are due to the very method of physical science.

Science, then, is not an adequate description of nature; it is a portrait, made by an observer with a particular point of view and a definite limitation on his vision. From natural science we cannot learn what material nature is for, how and why

[1] I deal throughout with physical science, but I believe that the situation would turn out to be fundamentally similar for the other sciences.

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it exists at all, and why it has any laws. In so far as we can answer these questions we do it in terms of a wider survey, made explicit in philosophy and theology, expressed concretely in poetry, felt and lived vividly in the nature-ecstasies of a few. 'The man of science who wishes to make his expert knowledge contributary to an absolute wisdom must first complete it by making it a full knowledge of nature, not in all her details, but in all her aspects.'[1] We recognize such wisdom as good in itself—a worthy part of the pattern of a good life. It is, moreover, useful in living the good life; for to live rationally man must know his situation; he must have some knowledge of nature, man, and God. More generally, science gives us a new window on life; we get a better notion of truth, goodness, and beauty in general through it, because it gives us a wider range of examples to compare. Science can enlarge our outlook on life. But it will do so only if we examine its presuppositions and probe its deficiencies; otherwise it may shutter our windows one by one.

I have dealt so far with the values of science considered as knowledge. But scientific *life* has its values, which are only partly determined by the values of the finished scientific knowledge. We must consider the other ways in which the good life for scientists is influenced by their work.

The first way is that scientific life is a simplified version or microcosm of rational life. This view was elaborated in an earlier article[2]: briefly, it was suggested that scientific life requires (*a*) an inquisitive care to establish facts, and (*b*) an effort to interpret and synthesize them, and therefore (*c*) a unity of thought and action; that (*d*) it is an example of a developing tradition, eager for novelty but tenacious of established truth; that (*e*) it needs freedom as well as some respect for authority, and that (*f*) it is in part a social and in part a personal enterprise. A further characteristic peculiar to science is that (*g*) scientific life needs manual skill as well as intellectual.

I suppose that when a man has a 'bent' towards science the reason is that his temperament and abilities fall in with this particular version of rational life. He likes the solidity of the data of science, the balance of fact and theory, the ease with which they are cross-checked. He likes the unending novelty of interpretation against the firm background of fact; the balance of change and stability, of settled presuppositions and new movements breaking their bonds. He likes the blend of freedom to put forward new evidence and any theory it will bear, with constraint due to the authority of old and proved results. He enjoys the balance of manual and intellectual work. If he is that rare being, a master scientist, he enjoys the balance of hard reasoning with intuition and imagination in making creative advances. Now, if scientific life is a version of rational life, it can be to some extent used as a school of rational life; it may be used to exhibit some of the principles of rational procedure in general. Its special qualification for this purpose (which is also an expression of its limitations) is that it does not require a mature wisdom or knowledge of the world, yet it introduces the mind to logical thought, and insists upon the need for experience and for complete fidelity to it when theorizing. Moreover it suggests problems which can only be solved philosophically—the problem of the validity of its own method, for instance. Science and wisdom, then, should not be wholly unconnected in a scientist's life.

It is not only the intellect that can be developed by scientific life, however, but the will as well. Science imposes a discipline that can leave as strong a mark on the character as can its stimulation on the intellect. Science, like all intellectual work, demands (to quote von Hugel) 'courage, patience, perseverance, candour, simplicity, self-oblivion, continuous generosity towards others, willing correction of even one's most cherished views.'[3] Again, like all learning, science demands a twofold attention, to brute facts and to the synthetic interpretation of them; and so it forbids a man to sink into himself and his selfish claims and shifts the centre of interest from himself to outside. But for scientists there is a special and peculiar discipline. Matter is perverse and difficult to make behave as one wants; the technique of experimental investigation is a hard and chastening battle. Nature seems not to care whether we can understand her or not; she hides her secrets, and her facts are great slayers of theories. It is in this contact with 'brute fact and iron law' that von Hugel found the basis of a modern and scientific asceticism, and in submission to this discipline that he found the detaching, de-subjectifying force that he believed so necessary to the good life.

Science, then, can help to stimulate the intellect and to discipline the will. To this extent it has bearings on the good life. But it cannot do this work alone: it must take its proper place in a

[1] F. Sherwood Taylor, *The Fourfold Vision*, chap. 6.
[2] ENDEAVOUR, April 1946.
[3] *Mystical Element of Religion*, ii, 349.

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liberal education and an open culture. The right use of science as a school of rational life depends on its being set in a matrix of other studies and other activities. Science by itself throws no light on its own value, nor on values in general. It is not a royal road to knowledge of every kind.

The upshot of this discussion, then, is this. Science, like other intellectual disciplines, has its own beauty and plays a part in revealing to us the beauty of nature. It is not unrelated to wisdom, though not wisdom itself. It can be integrated into the good life, though itself providing none of the principles of the good life. At every turn scientific life depends upon disciplines other than science. Without a liberal culture we shall miss most of the significance of science. The relevance of these conclusions to current thought on the place of science in human life is evident.

Book reviews

METALLIC CORROSION

Metallic Corrosion, Passivity and Protection, *by Ulick R. Evans, with an appendix by A. B. Winterbottom. Pp. xxxiv + 863. Edward Arnold, London. Second edition,* 1946. 50*s. net.*

That a second edition of this work should be required within eight years of its reprint speaks well both for author and scientific public. The volume is nearly 150 pp. larger than the earlier edition, but war-time reduction in the quality of the paper has roughly halved the thickness of the book. This makes it distinctly more convenient to handle, though the tendency of the type to show through is admittedly a disadvantage; but the publishers have made an excellent job of the obviously inferior materials at their disposal. All the same, a few plates illustrating various types of corrosion, micrographic structures, etc., would have relieved the puritanic text and broken the diagrammatic monotony. The book has been largely rewritten and much new material added, references as late as 1945 being included; this is excellent when one considers the long period that now elapses between proof-reading and publication. Apparently the detailed memoir of Logan and Romanoff, published in the United States in the autumn of 1944, did not reach England in time to be discussed in this book.

For the benefit of the non-academic reader a brief introduction to the principles of electrochemistry has been added to the forepart. Nine chapters are devoted to corrosion proper, four to protection, and one to methods of testing. One feels that the author might have done better by writing a separate volume on protective measures, as these are of great practical importance and deserve really thorough treatment. In the present volume the four chapters are inadequate, their chief value lying in their extensive bibliography. As part of a textbook, which is, apparently, the author's aim (*vide* p. iv), they are a failure. It is curious that under 'Random Errors' and 'Standard Error' (pp. 780–1), there should occur two of the very few grammatical errors in the volume. Generous acknowledgments are made to numerous authorities who have assisted the author in his arduous task.

J. NEWTON FRIEND

TREES IN BRITAIN

Trees in Britain, *by L. J. F. Brimble. Pp. x + 352. Macmillan & Company Limited, London.* 1946. 15*s. net.*

All those—and they must be very many—who read Mr Brimble's previous book *Flowers in Britain* will welcome this equally attractive successor. The British have always been tree-lovers, and here they and others will find much to charm them as well as instruct them. There are of course far fewer species of trees than of flowers in Britain, and this enables the author to make the treatment more detailed. The book is primarily intended for the general reader, and no knowledge of botany is assumed. Such botanical facts as are essential for the purpose are given in an introductory review of flowering plants. In the body of the book, the structure of trees, their classification, and their habits and habitats are considered, and special stress is laid on the part played by trees in folklore and literature. The colour plates have been prepared by artists who have specialized in painting trees, while some of the most attractive illustrations are reproductions of pencil drawings by the late Venerable Lonsdale Ragg. The book is well printed and produced and is decidedly one to possess.

CHROMATOGRAPHY

An Introduction to Chromatography, *by Trevor I. Williams. Pp. viii + 100. Blackie & Son Limited, London.* 1946. 10*s. net.*

The separation and purification of organic compounds by the method of chromatography is rapidly becoming of major importance in general laboratory practice. This book, written by one who has had considerable experience of the technique, is intended primarily for the student but will prove of equal value to research workers, who will readily find the information they normally require. Those desiring more detailed treatment of the subject will turn to the earlier monographs by Zechmeister and Cholnoky (English translation, 1941) and Strain (1942).

After a brief description of some of the pioneering work of Tswett on the separation of natural colouring matters over thirty-six years ago, an account is given of adsorbents, particularly alumina and its standardization, solvents, eluents used for the development of the columns, types of apparatus, and a considerable amount of information concerned with laboratory technique, illustrated by actual examples. The useful device of examining the columns in ultra-violet light is given due prominence, as is also the extension of chromatographic methods to the separation of colourless substances, including an account of the method of Tiselius. The separation of ions is a method of considerable potential value in inorganic analysis, and an account is given of the recent work of Martin and Synge on partition chromatography

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using silica gel. The final chapter gives some consideration to the theory underlying chromatographic analysis. The book is admirably written, well illustrated, and attractively printed.

W. BAKER

THE BLEACHING OF TEXTILES

An Introduction to Textile Bleaching, *by J. T. Marsh. Pp. xiii + 512, with 154 figures, including 32 plates. Chapman & Hall Limited, London.* 1946. 32*s. net.*

In *An Introduction to Textile Bleaching* the author has added yet another member to his excellent series of books on various aspects of textile chemistry and technology. It is a fitting companion to *An Introduction to the Chemistry of Cellulose* and *Mercerising*, and provides us with the first comprehensive review of a subject that has hitherto been scattered far and wide amongst the textile journals of the world.

The book is clearly written and thoroughly well organized, giving a valuable background of information in a form suitable either for the newcomer to the textile industry or for the experienced man who is progressive enough to be looking to science to help him in his work. The author has appreciated the importance of fundamentals, and devotes a considerable portion of his book to the structure of the various types of textile fibres; only when he has satisfied himself that this basic knowledge is sufficiently explained does he proceed to the discussion of textile bleaching itself. In this, Mr Marsh has set a precedent that could happily be followed up by other authors of this type of book; technical surveys are only too frequently spoiled by an inadequate discussion of first principles.

Today we are faced with an urgent problem in the modernization of the textile industry. The solution must, to a major degree, be dependent on the application of science and the scientific method in an industry that has grown up by rule-of-thumb procedure, and in order to do this we shall need efficient textbooks on textile science. Mr Marsh's series is helping to fill this void admirably.

J. G. COOK

A TEXTBOOK OF CHEMISTRY

General and Inorganic Chemistry for University Students, *by J. R. Partington. Pp. xxiii + 916. Macmillan & Company Limited, London.* 1946. 36*s. net.*

Professor Partington is well known as an accomplished expositor of chemistry, and his textbooks are always characterized by the accuracy of their contents and their readable but unadorned style. The present book is intended for the higher forms at school and junior students at universities, and for degree students as far as inorganic chemistry is concerned; for honours students the author hopes the book will serve as a companion to their studies.

The earlier part of the book deals with general and physical chemistry, and gives among much other matter an excellent account of the quantum theory of the atom. The elements are then dealt with in the order of the groups in the Periodic Table. Though this order is not without its disadvantages, no-one has yet succeeded in finding a better one, and in any case there is of course a natural basis for the periodic arrangement.

As in his *Textbook of Inorganic Chemistry for University Students*, Professor Partington here includes descriptions of experiments for lecture demonstration, and also gives a useful list of books on lecture experiments. Details of technical processes are in general omitted, and only modern processes are described except when an old process has some scientific interest. Numerous references to original papers and other sources are given, and the importance to all students of consulting some original papers is rightly emphasized. The amount of information in the book is very large, but it is so lucidly presented that the student will find no difficulty in assimilating or using it.

BIOCHEMICAL MICRO-ANALYSIS

Micro-Analysis in Medical Biochemistry, *by E. J. King. Pp. 168. J. & A. Churchill Limited, London.* 1946. 10*s.* 6*d. net.*

This book contains plain and precise instructions for the execution of all the routine biochemical investigations and analyses likely to be required in the pathological laboratory, including the preparation of reagents and the calculation of results. The book is more complete than its title might suggest, for some of the procedures, e.g. for urine, can hardly be classed as micromethods.

Apart from a table giving the 'normal' values for certain constituents of body fluids and faeces, another listing the clinical conditions associated with high or low values, and an occasional note in the text, there is no discussion of the interpretation of the findings. This is not to be expected, and in no way detracts from the book. Although the instructions are excellently clear and adequate, little or nothing is said of the limitations of the methods described, and references to fuller descriptions are rather scanty. The book is therefore not primarily for the student or for the clinician, but will be invaluable to all those actually examining or analysing clinical material.

The book is well produced, with pleasantly large type, and has useful chapters on colorimetric methods, simple spectroscopic procedures, and tests of function. It will certainly find a place on the shelf of every pathological laboratory.

N. G. HEATLEY

PHASE DIAGRAMS FOR AQUEOUS SOLUTIONS

Aqueous Solution and the Phase Diagram, *by Frederick Field Purdon and Victor Wallace Slater. Pp. iv + 168. Edward Arnold, London.* 1946. 24*s. net.*

In this very pleasingly produced work, the authors explain the construction of the phase diagrams of heterogeneous systems, and discuss very clearly and fully their interpretation. It is shown how, merely from a knowledge of geometrical principles, phase diagrams can be used to solve, both qualitatively and quantitatively, problems relating to the separation of pure substances from mixtures, the preparation of double compounds and hydrates, the cyclic re-use of mother liquors, the right amount of evaporation or dilution required to give the best economic result consistent with purity of product, and the effect of the addition of other salts or the accumulation of impurities. From these diagrams the progress of the various operations can be followed quantitatively and the optimum conditions ascertained. Only aqueous solutions, however, are here discussed.

For the practical worker, this book should prove of great value. The diagrams are clear and excellently drawn, and tables of experimental data are given from which the student can construct his own diagrams. The book can be heartily recommended, though the concluding chapter on Gibbs's Phase Rule is probably too short to be of much value.

ALEXANDER FINDLAY

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ENDEAVOUR

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The centenary of anaesthesia

It is impossible to assign the discovery of anaesthesia to any one person or to any one date, but so many events of fundamental importance in the history of anaesthetics occurred about a hundred years ago that the centenary of anaesthesia may rightly be commemorated at this time. In this connection it is appropriate to remember that, although anaesthetics are used almost exclusively by the medical and dental professions, their discovery and development owe much to the work of the pure scientist. The entire history of anaesthesia is, in fact, an illustration of the fruitful results of close collaboration between physicians and scientists.

Two outstandingly important dates in the history of anaesthesia are 16th October, 1846, when William Thomas Green Morton successfully demonstrated anaesthesia with ether before a gathering of surgeons at Boston, Massachusetts, and 4th November, 1847, when James Young Simpson and Drs Keith and Matthews Duncan recovered their senses underneath Simpson's dining-room table after testing chloroform, a drug 'far better and stronger than ether.' Chloroform and ether remained pre-eminent in surgical anaesthesia for decades, and both, despite the development and acceptance of many others, are still widely employed. These two events represented the culmination of earlier research by workers who, though they failed to achieve the goal of establishing anaesthesia in general medical practice, went far along the road towards it.

The first discovery of direct preliminary importance was the isolation of oxygen by Priestley in 1774. The physiological significance of the new gas was quickly appreciated by Lavoisier, who in the period 1774–85 elucidated the composition of the atmosphere and established the main principles of the respiratory process. These discoveries led to the development of pneumatic medicine, which concerned itself with the treatment of disease by the inhalation of gases. A noteworthy pioneer in pneumatic medicine was Thomas Beddoes, a lecturer in chemistry at Oxford. In 1794 he established the Pneumatic Institution at Clifton, Bristol, in order to pursue his investigations. One of the substances Beddoes studied was 'sulphuric ether,' the vapour of which he found to be of value in treating pains in the chest. Among those whom Beddoes attracted to Bristol was the young Humphry Davy. When Davy became superintendent of the Pneumatic Institute he was scarcely twenty years of age, but his enthusiasm for chemistry outweighed his youthful inexperience. One of his first tasks was to investigate the chemical and physiological properties of nitrous oxide, and in April 1799 he discovered that this gas was not only respirable but that, when respired, it produced a state of intoxication in which pain was deadened. He recognized the potential value of the gas in surgery, for in 1800 he wrote: 'nitrous oxide . . . appears capable of destroying physical pain, (and) it may probably be used with advantage during surgical operations in which no great effusion of blood takes place.' Unfortunately Davy himself made little effort to press this claim, so that the medical profession did not investigate it until many years later. Davy had, however, noticed another quality of nitrous oxide, namely its power of inducing a curious hilarity, which earned for it the name of 'laughing gas.' So pleasurable was the sensation that laughing-gas parties became popular in the early nineteenth century. It was owing to this frivolous application that the gas remained familiar and, nearly fifty years after Davy's original observations, eventually found its rightful place among surgical anaesthetics. In 1818 it was suggested, possibly by Michael Faraday, that ether vapour would produce the same kind of hilarity

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as nitrous oxide, and very soon ether too was inhaled at fashionable parties.

At about this time a British physician named Henry Hill Hickman, who practised in Shropshire, found that surgical operations could be painlessly performed on animals after causing them to inhale carbon dioxide. He published his results in 1824, but in the absence of any support from professional colleagues did not attempt to apply his method to human beings.

Meanwhile the fashion of laughing gas and ether frolics had spread to the United States. In the course of one of them C. W. Long, a physician of Georgia, observed that while under the influence of ether his guests often bruised themselves quite severely without feeling pain. In the period 1842–4 he successfully used ether anaesthesia for several minor surgical operations. In December 1844 a Connecticut dentist, Horace Wells, attended a nitrous oxide party and made the same observation as Long had done at the ether party. Next day he induced a colleague to extract one of his teeth for him after he had inhaled nitrous oxide. Wells felt no pain, and thenceforth used nitrous oxide anaesthesia in his dental practice. Unfortunately, when Wells and his fellow dentist Morton gave a public demonstration in Boston it was a failure, and his method was discredited. Morton was not discouraged, however, and determined to try ether vapour in place of nitrous oxide. On the advice of a chemical friend, C. T. Jackson, Morton procured a very pure sample of ether and used this successfully during the extraction of a tooth. On 16th October, 1846, Morton gave his now famous demonstration of the use of ether anaesthesia in surgery before a medical and scientific audience at Boston. This demonstration was a complete success. The sceptics were convinced, and the principle of ether anaesthesia was quickly accepted by the medical profession in the United States, in England, in France, and then throughout the world.

Thirteen months later James Young Simpson, seeking a more tractable substance than ether, successfully demonstrated in Edinburgh the valuable anaesthetic qualities of chloroform. Although this agent was soon found to be more dangerous than ether, the more precise control with which it could be administered soon made it the more popular of the two.

For many years the development of anaesthesia was confined to the perfection of techniques for administering chloroform, ether, and nitrous oxide. In 1884, however, a great step forward was made when Carl Koller introduced cocaine into ophthalmic surgery and this laid the foundation of the modern technique of local anaesthesia. In doing so he was in a sense reverting to a very old method, for such drugs as opium and mandragora were well known to the ancients as analgesics, and formed part of the normal equipment of physicians. Their use was, however, hazardous, owing to the absence of methods of standardization. Koller revived interest in substances of this kind at a time when medical and scientific knowledge was sufficiently developed to permit their use with comparative safety.

Chemists in particular quickly recognized the opportunities presented by the need for new and better anaesthetics. From investigation of the structures of natural substances such as cocaine and morphine they quickly turned to the synthesis of drugs unknown in nature, modelling them first on the natural products and later investigating totally new classes of compounds. In consequence the physician's choice of anaesthetics multiplied itself with almost bewildering rapidity. Ether, chloroform, and nitrous oxide remain in general use, but to them now must be added such substances as ethyl chloride, vinyl ether (vinesthene), trichlorethylene (trilene), cyclopropane, pentothal, kemithan, procaine, and nupercaine.

The use of anaesthetics in surgery was rightly described by Sir William Osler as the greatest single discovery in the history of medicine, and the contribution it has made, and is yet to make, to the relief of human suffering is immeasurable. At a time when the destructiveness of applied science tends to obscure its far greater services to human welfare, scientists may well pride themselves on their share both in the discovery and in the effective development of surgical anaesthesia.

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The influence of man on marine life

C. M. YONGE

Man's direct influence on marine life is of comparatively recent origin, for until about two hundred years ago the amount of fishing and whaling that was carried on was too small to upset the equilibrium of nature. With improved ships, apparatus, and technique, however, came a vast and indiscriminate slaughter of marine life, and some species were exterminated altogether. There is now a general realization that wise cultivation of the sea is as necessary as wise cultivation of the land. Professor Yonge gives a broad survey of the problem.

Man has had a profound effect on terrestrial life. Hunting, first with flint tools and eventually with precise weapons, led to the extinction, for instance, of the bear, wolf, and boar in Britain and to the almost complete extinction of the bison of North America. Like the big game of Africa, this animal has been saved only by tardy methods of conservation. Fur-bearing animals have been remorselessly trapped. The faunae of the earth have been irreparably impoverished by the senseless destruction of unique birds such as the dodo and the great auk. Cultivation of crops and domestication of animals modified plants and animals so greatly that the exact origin of some is now obscure, and also effected far-reaching changes in the balance of nature. The greater the crops, the more the pests—insects, rodents, and birds especially—that were attracted.

With the full discovery of the world by western man, his crops and domestic animals were introduced into the new lands of America, Africa, and Australasia, and many of the foreign plants were brought back—accompanied all too frequently by foreign pests. Often for sentimental reasons, hosts of other plants and animals were similarly transported. This indiscriminate mixing of fauna and of flora led to disasters such as the plague of rabbits and of prickly pear in Australia, and that of bramble thickets spread by the introduction of the starling into New Zealand. Man, in despair, turned to nature to redress the balance he had wantonly destroyed, and, after some failures, there were developed methods of biological control which today are clearing the prickly pear from Australia and destroying the aphid pests of Californian orchards. But, despite the rigorous care enforced by bitter experience, the spread of life continues. The chance introduction of a malaria-carrying mosquito, *Anopheles gambiae*, from West Africa into Brazil in 1930 caused a terrible epidemic, overcome only after heroic measures by the Rockefeller Foundation.

Life in the sea has been much less affected by man. In the obscurity of its depths and in the breadth of its oceans animals are difficult to hunt to extinction, while most of the marine vegetation and the bulk of the diverse invertebrate fauna are useless to man. In the sea, it has been said, man reaps without sowing, and this is largely true. It follows that in this case the responsibility of ownership which came with the domestication of animals and the care of crops has rarely displaced the unconsidered greed of the hunter. This is nowhere better shown than in man's pursuit of the marine mammals.

There are three groups of these: the sirenia or sea cows, the marine carnivora such as seals and walruses, and the cetacea comprising the whales, dolphins, and porpoises. The sirenia are a small group of obscure origin and grotesque form. They inhabit inshore and estuarine waters, feeding on marine vegetation. They consisted, until recently, of three groups, the Indo-Pacific dugong, the manatee of the tropical Atlantic, and the much larger northern sea cow of the North Pacific. The first two survive, although actively hunted—fortunately mainly by native tribes—for their flesh and blubber. The sea cow became extinct some thirty years after its discovery in 1741 by the young German naturalist Georg Steller, who accompanied Behring's pioneer voyage to the North Pacific. Under the greatest difficulties, while marooned with unwilling helpers on Behring Island, he dissected and described the animal. The Russian hunters and traders who followed Behring quickly exterminated it, and, apart from Steller's description, there remain for study only a few skeletons. The destruction of the sea cow is the greatest blow yet dealt by man to the marine fauna, equivalent to that of the equally remarkable, harmless, and locally distributed dodo.

The walrus once occurred in vast numbers throughout the north Pacific and the Atlantic, where it extended as far south as Nova Scotia and

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occasionally reached the shores of Britain. Following wholesale slaughter, such as that of 900 in one day near Spitsbergen in 1852 and that indicated by an annual import of 12,000 tusks into San Francisco alone between 1870 and 1880, it has become restricted to far northern waters. Many seals have suffered similar destruction, in particular those that breed in rookeries, like the Atlantic grey seal, and also the Greenland seal, which is the most important animal in the Newfoundland seal fishery, and the immense elephant seals (figure 1). Of these, the Californian species is now rare, but the naturalists of the *Discovery* Expedition found that the Antarctic species, which had been hunted on such a scale that it was reported virtually extinct a century ago, has reached a population of some 100,000 around South Georgia, where hunting is now annually confined to definite regions of the coast. A warm-water seal, once widely hunted in the West Indies, is now extremely rare.

These animals are sought for their blubber and flesh, but the eared seals, or sea lions, include the fur seals as much prized for their pelts as are sable, beaver, or silver fox on land. Formerly, various species abounded in northern and southern waters, but in the latter they have been almost exterminated, although there is some hope that they may be re-established in South Georgia. The greatest fishery of all was on the Pribilov Islands in the Behring Sea, some three hundred miles from Alaska. These islands were discovered by the Russians in 1786. There the vast rookery, with each huge bull gathering a harem sometimes exceeding one hundred females, and continuously fighting intruding males, must have presented an amazing spectacle. At the hands of Russian and American sealers upwards of two million seals were killed in fifty years. When the United States acquired the islands in 1867, attempts to control pelagic (open water) sealing in the Behring Sea led to international complications, and so to arbitration by a tribunal in Paris. This was followed by two Anglo-American commissions sent to the Pribilov Islands in 1891 and 1896–7. Eventually, pelagic sealing was prohibited by international agreement, and killing on the islands was restricted to the needs for food of the local population. Gradually the seal population recovered, and by confining hunting to the males, one bull to forty bearing cows being adequate for breeding, a rational control has been achieved.

It was the Russians also who discovered the delightful sea otter on the coast of Siberia. This rarest and most valuable of fur-bearing animals was hunted ruthlessly from there across the Aleutian Islands and south to California, where British and American hunters were at work. Almost complete extinction was again followed by international protection early in this century. Subsequent recovery has been slow, but populations of some two thousand in northern regions, and two hundred in southern, were estimated in 1939.

Helpless exposure on or near land invited slaughter of sea cows, seals, and sea otters. A similar fate has befallen the cetaceans, which include the largest animals ever to be evolved—the blue and fin whales—and which are so superbly adapted for aquatic life that they are even born in the sea. The tragic story of their ruthless hunting by man, which was begun by the Basques in the tenth century and has culminated in mass destruction by whale chasers operating from great factory ships in the Antarctic, has recently been related in ENDEAVOUR[1] and need not be retold.

Man the hunter has thus inflicted terrible loss on the marine mammals; fortunately it has not been worth his while, except in the one instance of the sea cow, to hunt them to final extinction. He has also, with the elaboration of increasingly efficient instruments of capture, made grave inroads into the stock of many of the more important food fishes. Here attention must be confined to the history of the European fishing grounds, in the exploitation of which Britain has played a leading part. The growth of the modern trawling industry dates from that of big industrial towns and the establishment of rapid transport between them and the fishing ports. The first North Sea trawlers came from Brixham in Devon. Originally in open boats, and later in two-masted smacks, the fishermen gradually extended their activities as far as the rich Dogger Bank. Towards the end of the last century steam trawlers employing the highly efficient otter trawl began to replace the sailing vessels, and to range as far north as the Barents Sea and as far south as Morocco. This wider range was necessary because the fish became increasingly fewer and smaller on the original grounds. Evidence of overfishing was given before a series of royal commissions but no action was taken, the extension of fishing to new areas tending to obscure the effects of depletion. Then came the war of 1914–18, which imposed a close season on fishing. The result after the war was striking: fish had

[1] L. Harrison Matthews, ENDEAVOUR, July 1946, p. 116.

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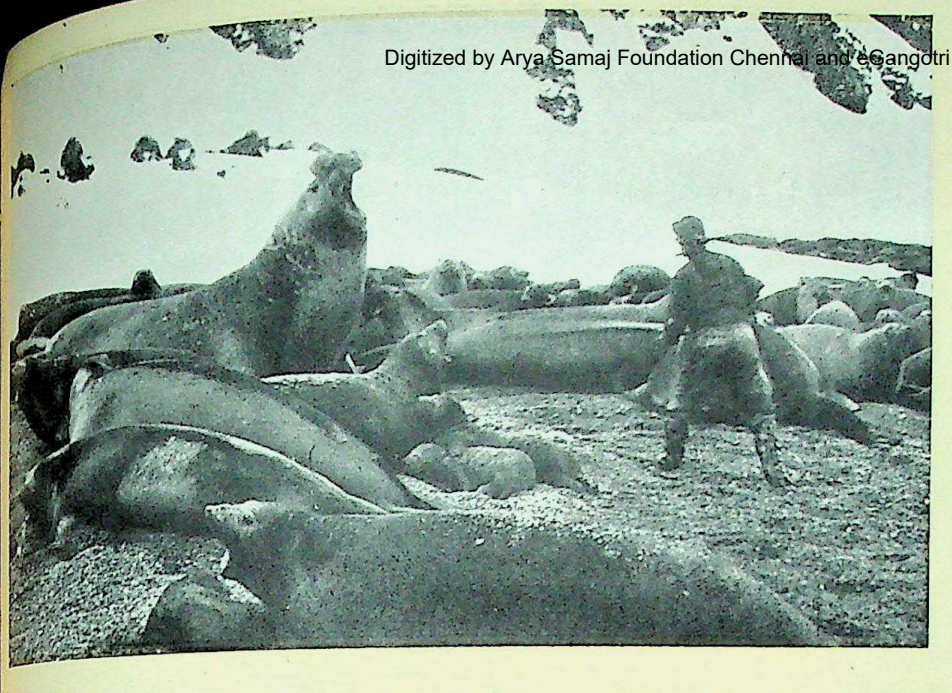

FIGURE 1 – *A herd of elephant seals on a beach in South Georgia. The figure of the sealer shows the size of the bull.*
(Reproduced by courtesy of Dr L. Harrison Matthews.)

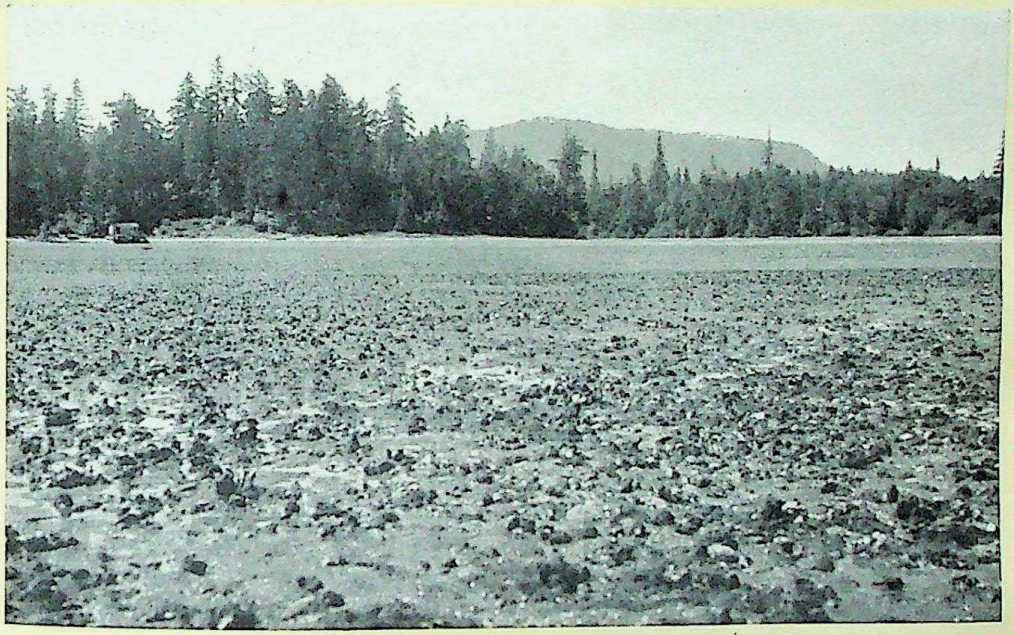

FIGURE 2 – *Japanese oysters* (Ostrea gigas) *in Ladysmith Bay, Vancouver Island, where they flourish after transplantation from Japan.*

FIGURE 3 – *The moat, Fort Jefferson, Tortugas Islands, Gulf of Mexico.*

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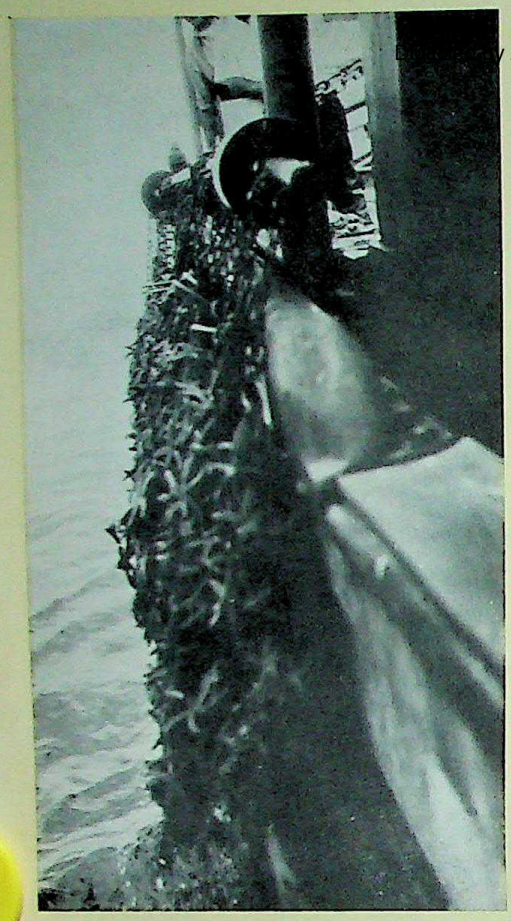

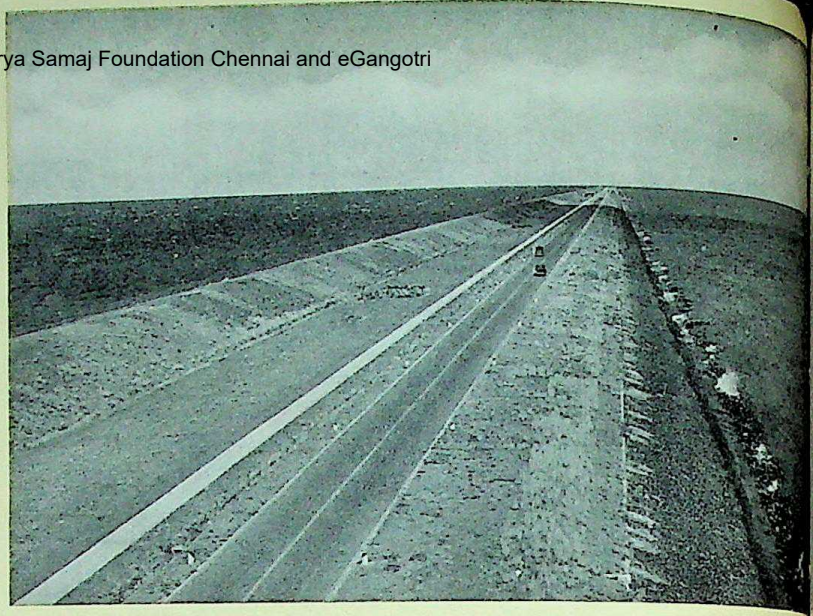

FIGURE 5 – *Zuider Zee dyke.*

Before this dyke was completed in 1932 *a thorough ecological survey was made of the region enclosed by it. Subsequent changes in both the environment and the population have been closely followed. The results of this conversion of a wide area of saline water into an inland lake have proved of great theoretical and practical importance.*

FIGURE 4 (*left*) – *Starfish collected by tangles from American oyster bed.*

increased in both numbers and size. In the period between the wars much of the scientific activity of the Ministry of Fisheries was devoted to working out and testing possible remedies for overfishing. This was the more necessary because as the years passed the effects of overfishing again became obvious. To take but one example of many cited by Dr E. S. Russell in his book *The Overfishing Problem*: the landings of haddock per day's fishing by English steam trawlers in the North Sea were 7·8 cwt. in 1906; this fell to 4·6 cwt. in 1914, rose to 15·8 in 1919, and had descended again to only 2·6 cwt. in 1937 (figure 6).

One obvious method of control is to enlarge the mesh of the vast trawl nets which annually sweep over practically the entire productive surface of the fishing grounds. This would enable the smaller fish to escape for further growth, and possibly reproduction, before capture. Another, more far-reaching, measure is to limit fishing. This demands a wide knowledge of the natural reproductivity of the fish. Unlike the marine mammals, with their annual or biennial production of one calf, fish produce vast numbers of eggs annually, of which only a few reach maturity. Food, though abundant, is not infinite, and growth is checked owing to intense competition. In other words, a certain degree of fishing is definitely helpful. It reduces competition and enables more fish to attain a large size. But clearly too intensive fishing has the reverse effect. It is a question of knowing exactly how much can be taken out with safety, so that man may obtain a rich harvest without adversely affecting natural stocks. It is actually not only more economical to fish with fewer vessels but the yield may in fact be greater than if too many are employed and the effects of overfishing produced.

Despite the size and obscurity of the fishing grounds, the basic facts concerning the productivity of the chief north Atlantic food fishes are known. This is due to the labours of the scientific staffs of the English and Scottish fishery services and those of the other maritime countries of western Europe. All normally work in close co-operation through the International Council for the Exploration of the Sea. It is now possible to formulate measures of control which, when aided

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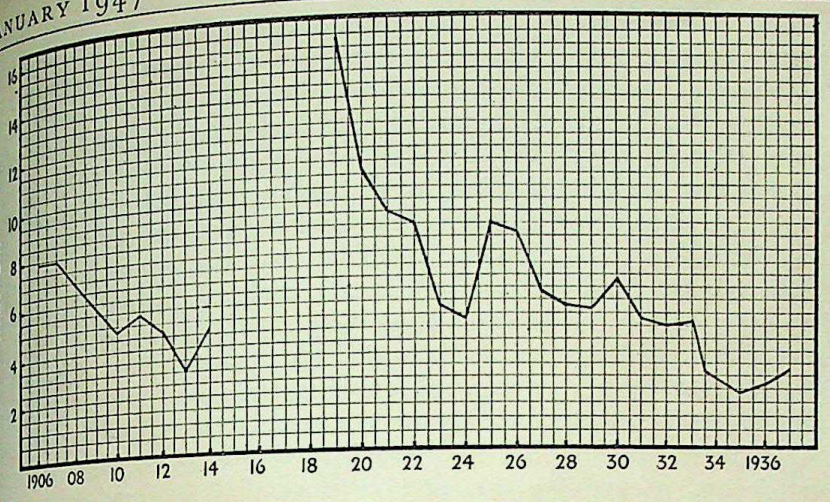

FIGURE 6 – *Graph showing weight (in cwt.) of haddock landed per day's absence by English steam trawlers in the North Sea. The effect of overfishing before and after the* 1914–18 *war, marked by the break in the graph, is well shown.*
(*Data from* The Overfishing Problem, *by E. S. Russell.*)

by continuous scientific supervision, will permit a rational exploitation of the fishing grounds. How successful such action may be is well shown by the result of treaties made between the United States and Canada in 1924 and 1930, and renewed in 1937, for the control of the Pacific halibut fishery, in which both countries are interested. An international fisheries commission was set up, and the fishery, which had undergone catastrophic decline, has recovered to a striking extent after limitation of fishing. In such rapid recovery we see the result of the great fecundity of fish. Populations of whales or seals may take a century to recover fully after too intensive hunting; those of fish will recover in a much shorter time.

Today, after the second close season imposed by war within a generation, there is clearly an opportunity for conserving the now well-stocked fishing grounds of western Europe. The British Government is certainly of this opinion. At its invitation an international overfishing conference was held in London not long after the end of the war. Representatives of all the maritime nations of western Europe except Germany attended, and considered the possibility of agreeing on measures for regulating fishing in the North Sea and adjacent areas. With the needs of starving populations constantly in mind far-reaching decisions could hardly be expected, but agreement was reached on an increase in the size of the mesh of trawl nets and also on size limits for the twelve most important bottom-living food fishes. Limitation of the tonnage of the fishing fleets of the different countries, which was proposed by Great Britain, was not accepted, but the reality of the problem of overfishing was realized to the extent that an advisory committee was appointed to study the matter and propose suitable regulations for the prevention of overfishing in the North Sea and adjacent areas. There is thus some real ground for hope that in the future the fisheries of Europe may, like those of the north Pacific, pass from an era of over-reaching greed to one of rational exploitation based on conservation of the stocks.

Aquiculture, or the cultivation of aquatic life, has been conducted on a very limited scale compared with agriculture. With the exception of some cultivation in Japan of seaweeds from which agar is obtained, it is, moreover, restricted to animals. Its greatest, and by no means negligible, triumph has lain in the cultivation of oysters and other bivalves.

The aim of aquiculture is to increase some part of the population, either in numbers or in size of individuals. This may be done by improving their chances of survival, by transplanting them to regions where food is more abundant, or by increasing the fertility of confined waters. Although there is evidence that the Romans practised crude methods of oyster cultivation in Lake Fusaro and elsewhere, modern cultivation may be said to date from the work of Costé on the French oyster beds. These one-time prolific areas became progressively more depleted as a result of increasing demands from the growing industrial cities during the middle of the last century. Costé realized the fundamental fact that the oyster produces immense numbers of free-swimming larvae, but that only a minute fraction of these find the requisite clean, hard surface for settlement when they sink to the bottom. From his suggestions and experiments arose the modern method of putting out 'collectors,' consisting of half-cylindrical roofing tiles encrusted with lime and sand, in the early summer, when the oysters are ready to spawn. In this way millions of oyster 'spat' find surface for settlement. Costé further

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realized the need for protection. After some months of growth, the young oysters are flaked off the tiles and transferred to 'ambulances,' where they are protected by wire netting from their numerous enemies such as crabs, starfish, rays, and marine snails. Later still the oysters are laid out on extensive parks, from which intruders are removed at low tide. Today the vast area of these parks around the shallow, almost land-locked bay of Arcachon, and in other regions of the French coast, are evidence of a flourishing industry. The French also found that oysters would grow and 'fatten' in areas where they will not necessarily breed, and began to transplant oysters into shallow lagoons or 'claires,' particularly around Marennes. In these warm waters the microscopic suspended plant life, or phytoplankton, on which the oysters feed increases rapidly. By such methods a highly organized and immensely productive oyster industry has been built up along the Atlantic coasts of France.

Similar methods, involving provision of settling surface, removal of pests, and transplantation to better feeding grounds, have been developed in many other countries, especially the United States. In the Delaware River, for instance, a natural breeding area some distance up the estuary is maintained, and a collecting surface, in this case consisting of masses of clean oyster shells spread loose or in wire-netting bags, is provided. These shells are later dredged up, the young oysters separated, and a proportion laid on planting beds nearer the sea, where they rapidly grow. The beds are regularly swept with wide-spreading cotton tangles (figure 4) in which the invading starfish are collected in millions, while continuous warfare is waged against other pests. The output of this one oyster fishery runs into some four hundred millions annually.

Along stretches of the Atlantic coast the French also cultivate mussels on long fences of piles and wattling driven into the mud flats. This *bouchot* system was introduced by an Irishman named Walton, who was the sole survivor from a small vessel wrecked in 1235 in the Anse de l'Aiguillon. On the muddy shores of this shallow bay, widely exposed at low tide, he is said to have driven stakes for the attachment of roughly woven grass nets in which he hoped to snare sea birds. He soon found that his nets became covered with mussels, which grew much larger than those on the shore and which proved an excellent source of food. He then took to planting stakes with interwoven twigs between them and so established the simple form of cultivation which still persists.

Modern examples of successful cultivation of bivalves include the unique pearl shell farm at Dongonab in the Red Sea, developed by the late Dr C. Crossland from 1905 until 1923, when a decline in the price of pearl shell caused its abandonment, and the culture pearl industry in Japan. Small beads which form the nucleus of future pearls are enclosed within pieces of the shell-forming tissues of a pearl oyster, and the whole, by a delicate operation, is grafted into the tissues of an intact oyster. A very different animal, the commercial sponge, offers possibilities to the cultivator. It grows attached like a plant, and cuttings may be made which will round off and grow under suitable conditions.

Transplantation of marine animals over great distances raises much greater problems than does that of terrestrial animals. If climate and food are suitable, many domestic and other animals may flourish in the southern hemisphere or in North America as well as, or even better than, they did in their original home in the Old World. Fresh-water fishes may also be transported successfully, as the teeming populations of trout and other fish introduced into the rivers and lakes of New Zealand bear witness. But with marine fish there is the additional factor of spawning migrations. In general, fish grow on their feeding grounds but then migrate against the prevailing currents to spawning areas characterized by very sharply defined physical and chemical conditions. From these the small, surface-dwelling larvae are carried passively back by the currents to the adult feeding grounds, sometimes by way of 'nursery' areas. Thus, though an adult fish may feed and grow in new surroundings, the whole complex mechanism of spawning migrations is upset, and the animals fail to establish themselves. Attempts to introduce herring into New Zealand waters failed probably for this reason. Atlantic salmon, successfully introduced into the rivers, apparently failed to find their way back to the rivers where they must spawn after feeding and growing in the sea.

On the other hand, transplantation over limited distances is possible. Marked plaice have been transplanted from coastal waters to the rich feeding grounds of the Dogger Bank and have there grown much faster than similar animals on the original grounds. The Danes have successfully transplanted small plaice from the crowded waters of the North Sea to the richer feeding grounds of the Limfjord.

It is also possible to transplant some marine

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invertebrates which live and spawn in the same place, usually in shallow water. Oysters and other bivalves are normally 'relayed' on a large scale, although attempts to establish lobsters, which have a more complicated life-history, into New Zealand waters have failed. In Great Britain, where the population of 'native' oysters has greatly declined, young or 'seed' oysters have been purchased from France or the United States. Some of those from France have been of the same species as the 'native,' *Ostrea edulis*, but many have been Portuguese oysters, *O. angulata*, which colonized the southern parts of the French Atlantic coast during the past half-century. This oyster grows well on British beds but never spawns, and so can never become established here. It is indeed the spawning temperature, rather than the temperature at which the adult can live, that largely controls the distribution of marine invertebrates. *Ostrea edulis* spawns when the temperature reaches about 15° C, but *O. angulata* does not spawn until 20° C, which is not attained round our coasts. The same difficulty was found when the Japanese oyster, *O. gigas*, was introduced along the Pacific coasts of North America to replace the smaller local species. The temperature is rarely high enough to permit natural spawning, but some success was achieved in the summer months by placing the oysters in floats where the water reached a higher temperature than on the bottom. Later, successful use was made of discoveries by Dr P. S. Galtsoff of the United States Bureau of Fisheries, who found that oysters will breed at lower temperatures if stimulated by the presence of their own genital products in the water. In Vancouver, the Japanese oyster (figure 2) has been regularly induced to spawn by pouring suspensions of ripe egg and sperm, obtained from the sheds where oysters are opened and canned, over the beds at the height of the summer.

So far as we have discussed it, cultivation in the sea consists of ensuring high survival rate of certain stocks in areas where food is abundant. Increase in available food, as produced on land by the use of fertilizers, is still in the experimental stage in aquiculture. The 'fattening' of oysters in the *claires* at Marennes is due to the enrichment of the water by seepage of nutrient salts from the land, the rich microscopic flora so ensured forming food for the oysters. In limited masses of water, fertilization by addition of nutrient salts containing available nitrogen and phosphorus is feasible, and initial experiments by Norwegian and Danish biologists have revealed significant increases in plant and animal life. Similar experiments, aimed at an eventual enrichment of the local stocks of fish, have been carried out during recent years in small lochs along the west coast of Scotland.

The dispersal of the fauna of the land by the activities of man is in no way paralleled in the sea. Some of the reasons for this, such as the association of breeding migrations in fish with ocean currents, and the influence of temperature on the breeding of many marine animals, have been noted. Nevertheless species have been carried to new areas either deliberately, as in the case of the oysters, or else accidentally. When American oysters were relaid on British beds they were accompanied by the slipper limpet, *Crepidula*. This was first noted in the eighties of last century and now extends from the Humber round the south coast as far as Dorset. Unlike the species of oyster which it accompanied here, it is able to breed within the range of temperature found around our coasts and has firmly established itself. It is now a major pest on many British oyster beds. Some twenty years ago it was found on the coasts of Holland, where it had apparently been transported across the North Sea attached to floating wreckage or possibly seaweed. Within ten years it had become a serious pest there also, and had also spread north to the coasts of Germany and Denmark. During the hard years of the recent war the Dutch were driven to utilize this previously unwelcome visitor as a source of human food.

There remain to be mentioned the effects of major engineering works on marine life. The author was first struck by these during a visit to the Carnegie Marine Biological Laboratory on the Tortugas Islands in the Gulf of Mexico. On one of the sandy coral cays arises the immense brick erection of Fort Jefferson, now derelict (figure 3). This is surrounded by a moat which was originally in free communication with the sea and in which became established a representative sample of corals and other marine organisms. In 1919, hurricane seas breached the moat, sand and debris were carried in, and free circulation ceased: it became a sediment trap. In 1934 the fauna of the moat was very different from that when the sea had free access. Only those organisms which could withstand silty conditions survived, and these included only one out of originally seven species of corals, namely *Siderastrea radians*. But the most noteworthy fact was that many of these colonies had become more rounded and had

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changed in skeletal form; in this way they had become capable of living in water where there was a continuous fall of sediment.

One of the greatest feats of marine engineering was the cutting of the Suez Canal (figure 7). In 1924, fifty-five years after the canal was opened, the fauna was studied by a Cambridge University expedition under Professor H. Munro Fox. The greatest barrier to the migration of animals through the canal is the high salinity of the Bitter Lakes, originally a dry valley but with salty deposits resulting from the drying up of a former northward extension of the waters of the Gulf of Suez. To a less extent the narrowness of the canal proper, and the stirring up of water in it by the passage of boats, affect large and small animals respectively. But despite these factors and the high temperature of the shallow water, there is now a representative marine fauna in the waters of the canal and its lakes. The animals are predominantly Red Sea species, because powerful currents flow from the Red Sea into the Bitter Lakes, while there is a slow current from there into the Mediterranean for ten months of the year. Only in fish are Mediterranean species well represented, because these move independently of currents. The invertebrate animals are distributed mainly during the drifting planktonic stage of the life-history and so are at the mercy of prevailing currents. Gradually, representatives of the Indian Ocean fauna are passing through into the Mediterranean, where two of them, a pearl oyster and a swimming crab, are now firmly established.

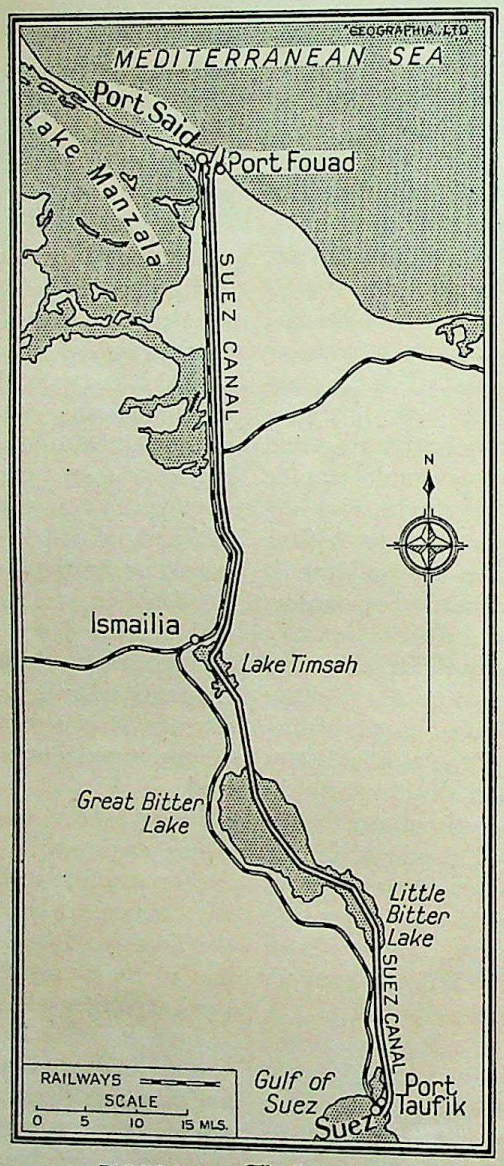

FIGURE 7 – *The Suez Canal.*

The Dutch, in the latest and greatest of their battles with the sea, completed a great dyke (figure 5) across the mouth of the Zuider Zee in June 1932. By so doing they converted a wide area of saline water into a great inland lake. Before the dyke was finished a thorough survey of the animals and plants within the Zuider Zee was made, and subsequent changes in both the environment and the population were closely followed. Originally the latter consisted of a somewhat restricted though essentially marine community, but included a number of endemic species of both plants and animals. Decrease in salinity was accompanied by rise in nutrient salts and so in basic fertility, and there was a widespread change in the fauna and flora. Purely marine species, such as herring, anchovies, plaice, mussels, cockles, and crabs, and also a seal colony on the island of Urk, all disappeared. Porpoises were asphyxiated under the ice which formed on the now fresh water. Brackish-water or estuarine species, notably the solitary endemic crab, maintained themselves to some extent, but fresh water forms which migrated down from the rivers became dominant within two years after the completion of the dyke. These included bass and carp among fish, many fresh-water plants, and also invertebrates such as the harlequin fly, *Chironomus*, which breeds in water. This became so numerous in the initial absence of enemies, that the hordes of flies arising from the water blocked the radiators of cars driving over the dyke.

After the repair of damage suffered during the war, the eventual outcome of this major change brought about by the activities of man will be the conversion of a shallow arm of the sea into a restricted and reed-bordered lake. This will be rich in fresh-water life but will probably contain a few curious remains as sole evidence of its original saline character.

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Sydney Young, 1857–1937

J. TIMMERMANS

The preparation of organic compounds of a very high degree of purity is of great practical and theoretical importance. To the experimentalist Sydney Young we owe both recognition of the significance of such substances and the development of elegant new practical methods of obtaining them. Young's eminently reliable work influenced that of scientists in many countries and especially in Belgium, where there was already a well-established tradition in the preparation of pure organic compounds for stoichiometric and other studies.

Gas chemistry has always held a place of honour in Great Britain, where much fundamental research on gases has been done. The names of Boyle, Hales, Priestley, Dalton, Cavendish, Davy, Faraday, Andrews, Dewar, and Ramsay immediately spring to one's mind in connection with research in this field. These scientists will always be remembered for the originality of their work. After the early explorers who daringly advance into the unknown come the settlers who take possession of the land and occupy it permanently. In the realm of science this second generation is represented by the experimental scientists whose aim is to establish a precise measuring technique. The reputation of these meticulous workers is more slowly established because their work is less spectacular, but with the passing of time the importance of such investigations as an indestructible basis for further progress becomes apparent. Sydney Young is an important representative of this class of scientific worker—critical rather than creative, but eminently reliable.

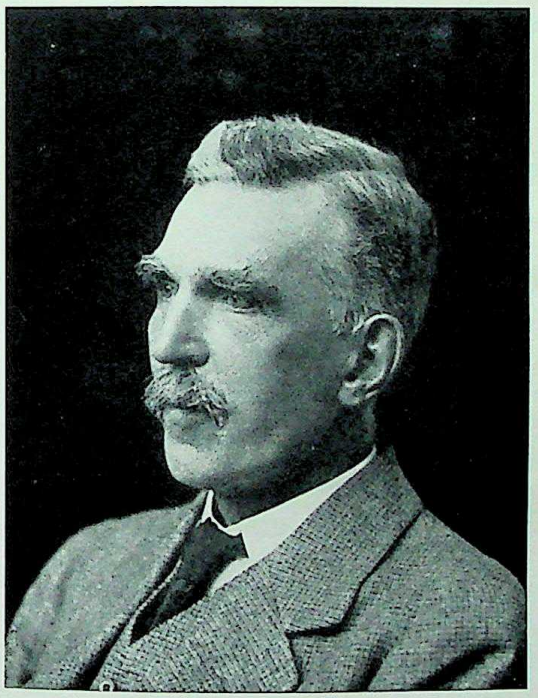

FIGURE 1 – *Sydney Young.*

Young, a Lancashire man, studied under Roscoe and Schorlemmer at Owens College, Manchester, and under Fittig at Strasbourg. He obtained his degree as Doctor of Science in 1883, while working with Ramsay at University College, London, where he graduated in 1880. In 1887 he succeeded Ramsay as Professor of Chemistry at University College, Bristol, a position which he occupied for the next fifteen years: this was the most fruitful period of his scientific career. In 1903, at the age of 46, he became Professor of Chemistry at Trinity College, Dublin. There the burden of work connected with teaching and examinations left him time for little more than theoretical interpretations of his earlier experiments. He was chairman of the chemistry section at the Annual Meeting of the British Association at Cambridge in 1904, chairman of the Royal Irish Academy, and a Fellow of the Royal Society.

This is not the place for a detailed chronological account of Young's researches or of the papers he published. This may be found in the excellent biographical studies made by his successor at Bristol, Professor Francis Francis (*Journal of the Chemical Society*, 1937, 1332), and by his old pupil in Dublin, Dr W. R. G. Atkins (*Royal Society Obituary Notices*, 1937, **2**, 371). Here it will suffice to give a general outline of the activities of the great experimentalist. There was a remarkable uniformity in his career; he devoted some twenty years of his life to a study of the thermodynamic properties of, and the heterogeneous equilibria between, about thirty highly purified organic compounds. The results of these researches appeared in 1908 in his book *Stoichiometry*. In preparing the pure substances required for his researches he improved the existing methods and apparatus used for fractional distillation. His observations

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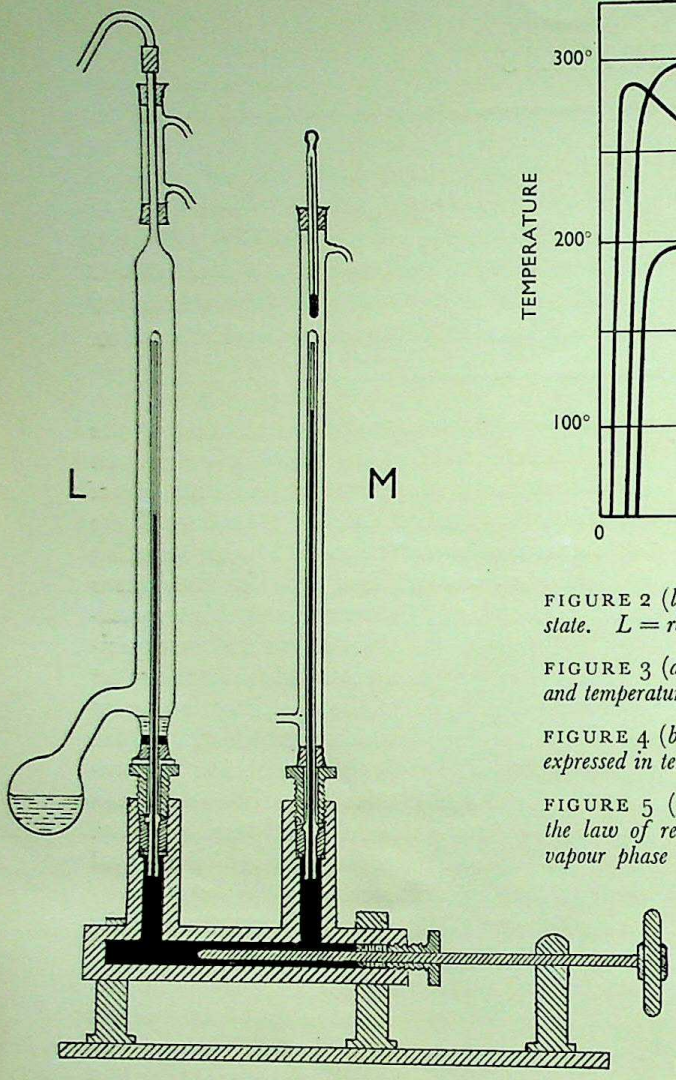


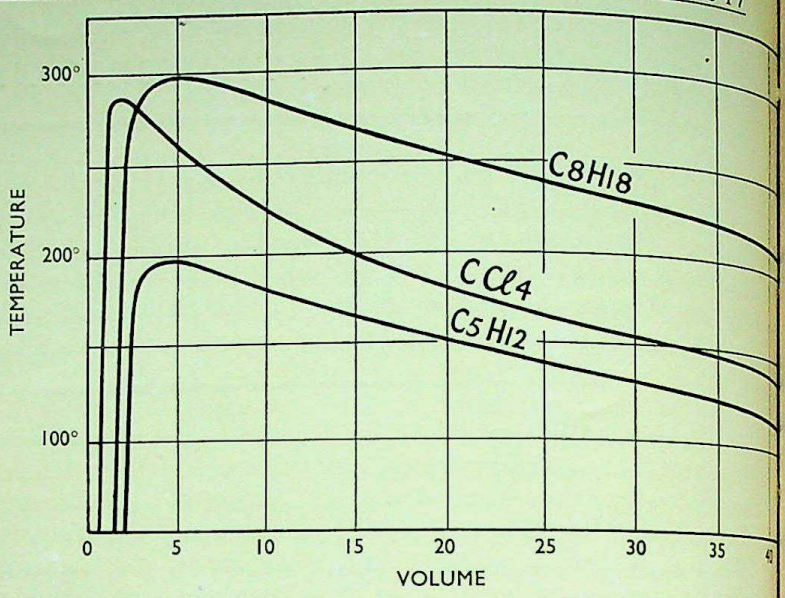
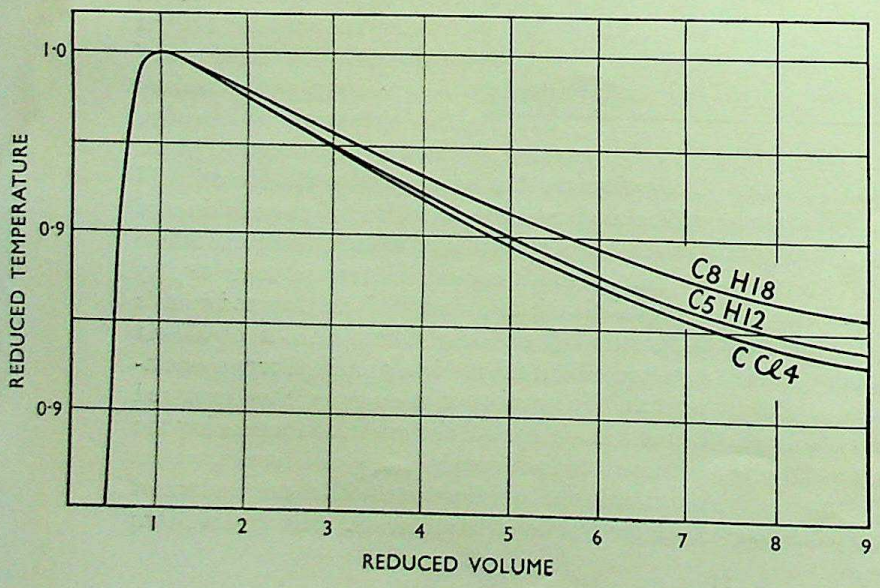


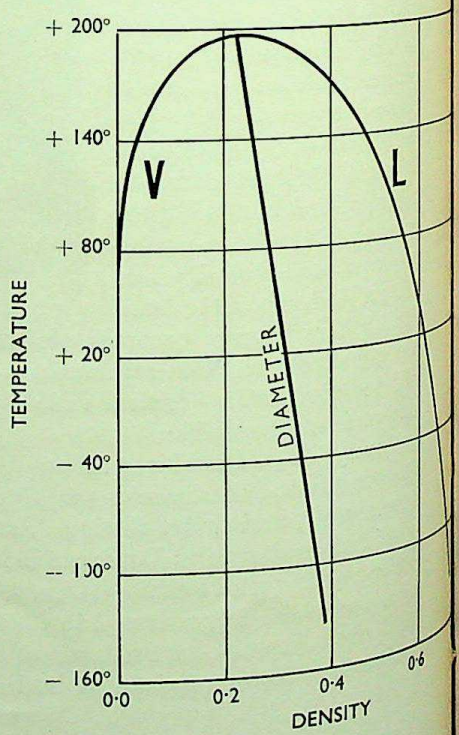
FIGURE 2 (*left*) – *Ramsay-Young apparatus for studying the equation of state.* L = *reaction tube.* M = *gas manometer.*

FIGURE 3 (*above*) – *Specific volumes of liquid and saturated vapour in c.c. and temperature in degrees Centigrade (orthobaric volumes).*

FIGURE 4 (*below, left*) – *Reduced orthobaric volumes of the same substances expressed in terms of critical volume and critical temperature.*

FIGURE 5 (*below, right*) – *Orthobaric density of n-pentane, illustrating the law of rectilinear diameters* (*see page* 13). V *represents the saturated vapour phase and* L *the liquid.*





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in this field were embodied in a second treatise, *Distillation, Principles and Processes*, of which the first edition was published in 1922.

Young's first experiments on heterogeneous equilibria were suggested to him by Roscoe and carried out under the supervision of Ramsay. Their object was to examine the behaviour of saturated vapour, crystal, and liquid phases in the neighbourhood of the triple point. Shortly afterwards, however, he specialized in precise determinations of the thermal constants, density, vapour pressure, and critical constants of a great number of organic substances, such as acetic acid, benzene and its halogenated derivatives, cyclohexane, paraffins, carbon tetrachloride, alcohols, and esters of the fatty acids. These researches established for Young a reputation for impeccable precision. As his means were limited he built his own glass apparatus—these are models of ingenuity and simplicity (figure 2). In making determinations of temperature, specific volume, and saturated vapour pressure he not only took the greatest care in making all the corrections needed for the high accuracy he achieved, but managed to avoid making his technique unnecessarily complicated. His mastery of technique is illustrated by his use of ordinary thermometers, graduated in degrees on the stem, for his extremely precise measurements of temperature. These thermometers were, however, prepared with great care. To avoid variations in the zero point they were annealed in a bath of boiling naphthalene. He himself made the table of corrections for all parts of the scale by suspending the thermometer in vapour from pure boiling liquids, a method still regarded as giving reliable standards. The accuracy of his results is such that even after fifty years they remain unquestioned.

Young's magnificent work in the determination of constants is important not only because it gives so many precise data relating to fundamental experiments, but because it is of significance in assessing the validity of the equation of van der Waals. Young was able to demonstrate that, generally speaking, his quantitative results conformed well with theory at every point, but that certain numerical coefficients had to be altered. For example, the critical coefficient $D_{cr.}/D_{calc.}$, where $D_{calc.}$ is the density (specific volume) obtained by applying the laws of perfect gases at the critical temperature and pressure, was assigned the value 2·7 by van der Waals, whereas observation gives the value 3·8. The theory of corresponding states is more accurate than the equation of van der Waals from which it is derived (see figures 3 and 4). Young also tested very carefully the so-called law of rectilinear diameters, which states that if the mean of the densities of the liquid and saturated vapour at any temperature be plotted against the temperature, the points so obtained will lie on a straight line. In only one case, that of normal pentane, was the law exactly followed; the curves for all the other liquids examined showed a slight but distinct curvature. (See figure 5.)

The care taken by Young in the execution of his very precise measurements places him on the level of physicists like Regnault. His pioneering work lay in the preparation of organic compounds in a state of high purity, for his exact determinations of the critical constants of a large number of substances showed him how sensitive these constants are to traces of impurities. Before his time only Mendelejeff, using ethyl alcohol, and de Visser, using acetic acid, had demonstrated the possibility of preparing completely homogeneous, anhydrous organic substances characterized by the constancy of their physical properties. Young verified this for a large number of substances, and his success was such that, in the great majority of cases, his values are still accepted as standards today. There again he devised methods of overcoming difficulties which were so simple and effective that they are still used.

His experimental work entailed the determination of the boiling-points of a large number of homologous compounds in various organic series. He was able to demonstrate that on the Kelvin scale the difference (Δ) between the boiling-points, at normal pressures, of two successive members of such series depends only upon the boiling-point of the first member. In general the results conform well with the general formula

$$\Delta = 144{\cdot}86/T^{0{\cdot}0148\sqrt{T}}$$

This is one of the few stoichiometric relationships which have real quantitative significance.

His work on the preparation of pure substances compelled Young to devise improvements in the methods of distillation and in the design of dephlegmators then in use. The 'evaporator still-head' and column of Young and Thomas was the first apparatus which made possible the separation of *n*-pentane (boiling-point 34·5° C) from *iso*pentane (boiling-point 29·0° C), both of which are contained in light petroleum.

To Young also we owe both new experimental methods, and new ways of representing the

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resulting data, which have proved of great practical importance in the laboratory and in industry. He discovered large numbers of azeotropic mixtures and pointed out simple methods of determining their composition: this opened a new and very fruitful field of science. He determined the exact composition of some ternary azeotropic mixtures, and his process for the dehydration of ethyl alcohol by elimination of the water in the form of a ternary azeotropic mixture with benzene has been employed in the Kahlbaum works in Germany.

While Young was engaged in this important research during the last decade of the nineteenth century, several other British scientists were also engaged in the study of very pure substances. Perkin was interested on account of his work on magnetic rotatory power, and Thorpe because of his measurements of viscosity. Although Young did not establish a school of his own in England, his work has long influenced foreign scientists, particularly in Belgium and in the United States.

Belgian chemists had a well-established tradition of particularly conscientious work in connection with the preparation of pure substances. This work was originated by Jean Servais Stas, who required perfectly pure materials for his determinations of atomic weights, and by Léon Crismer, who demonstrated the importance of the critical temperature of dissolution as a simple and highly sensitive criterion of purity. Crismer used this test to establish the most efficient methods for completely drying methyl alcohol and its homologues. When Belgian chemists became aware of the work of Young there was a swift development of the techniques necessary for the study of pure organic compounds. Chavanne improved the methods used for the identification of mineral oils of different origins, submitting them to fractional distillation and comparing with synthetic samples the fractions so obtained. The work of Chavanne's pupils is marked by the particular care taken in the purification and identification of organic substances. At the University of Louvain, Louis Henry had always attached great importance to stoichiometric relationships in organic chemistry, a study which involves the use of pure reagents. In this connection, Pierre Bruylants and his school have done brilliant research on density and refractive index in the paraffin series. At Ghent, the work of Frédéric Swarts, to whom we owe the characterization of most known organic compounds of fluorine, is marked by the care taken in the purification of samples used for some of the determinations, notably for measurements of refractive index and heat of combustion.

This combination of favourable circumstances led to the creation in Brussels, in 1921, under the auspices of the Union Internationale de Chimie, of the Bureau of Physico-chemical Standards, where the main physical constants of nearly two hundred of the commonest organic compounds have been accurately determined. It was in Brussels too that Lecat started his chemical researches, now so extensive and fruitful, in the field of azeotropism.

In the United States, departments of the Bureau of Standards in Washington have undertaken, under the guidance of Professor Washburn, some important work on the identification of very pure petroleum hydrocarbons, and on their heats of combustion. Other researches, notably those carried out in California, relating to the measurement of changes in entropy, have necessarily led to the preparation of great numbers of pure organic compounds. In the United States the influence of Young is also felt, though indirectly, through two former students of the University of Brussels. Albert Henne, professor at Columbus University, Ohio, has done fine work on organic compounds of fluorine which combines characteristics of the schools of both Chavanne and Swarts. Georges Callingaert, director of the research department of the Ethyl Gasoline Corporation, Detroit, has successfully undertaken the study of very pure hydrocarbons.

It is thus evident that the example set by Young has started several important schools of research on pure organic compounds. Scientific workers had too long been content to deduce so-called constants from measurements carried out on only approximately purified samples, and there was a manifest discrepancy between the accepted standards of chemical purity and the standards of accurate physical measurement. In the inorganic field it had long been recognized that each definite compound is characterized by physical constants which, provided the process of purification has been properly carried out, are independent of the origin of the sample. The instability of organic substances, together with the difficulty of purifying them and of keeping them pure, led to the belief that this was not so in organic chemistry. It is to Young that we owe the convincing demonstration that a pure organic substance is as precisely defined as one of the elements themselves, and on this rests his main title to fame.

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Some applications of optical crystallography

N. H. HARTSHORNE

During the last fifteen or twenty years, the polarizing microscope has proved its worth in the identification and analysis of solid substances, not only in pure science but in industry and technology. By its use, for example, members of a series of closely related compounds may easily be distinguished from one another, the individuals in solid mixtures of salts can be identified, organic stereoisomers may be differentiated, and the nature of the solid phases in such forbidding systems as high-temperature silicate mixtures can be ascertained.

The determination of the optical properties of transparent crystalline substances by means of the polarizing microscope forms, as is well known, the basis of a standard petrological technique for differentiating and identifying the mineral species in rocks. It is perhaps not so well known that this method of identification has also found many useful applications in other fields, notably in general chemical practice and in the study of a variety of natural and industrial products, including refractories, slags, building cements, explosives, plastics, and textile fibres. Several authors [1] have drawn attention to the wide applicability of the method, which is illustrated in the present article. For greater clarity it has been thought desirable also to include an outline of the underlying principles of the method.

Two other crystallographic methods of identification are based respectively on the measurement of characteristic interfacial angles, and the use of X-ray powder spectrograms as 'fingerprints.' The first of these can be applied only to well-formed crystals of individual compounds which are large enough to be mounted on a goniometer. The second method can be directly applied to mixtures, and is particularly useful when the state of division of the material is near, or less than, the limit of microscopic resolution. But where this is not so, it will commonly be found that the optical method is quicker, simpler, and more appropriate. Moreover this method has the advantage that it gives direct information about the texture of the specimen, the form and size of its particles, and, if it is a mixture, the distribution of its ingredients, all of which may be of prime importance in the problem on hand.

The essential features of crystal optics are as follows. Crystals of the cubic system are *isotropic* to light, that is, light passes through them with the same velocity in all directions. Crystals of all other systems are *anisotropic*: their structure and therefore their physical properties, including the velocity of propagation of light, are different in different directions. When a beam of light enters such a crystal, it is in general refracted into two beams which have different velocities and are polarized in planes at right angles to one another. There are, however, certain directions called *optic axes* along which this double refraction does not occur. Tetragonal, hexagonal, and trigonal crystals have one such direction and are therefore termed *uniaxial*; orthorhombic, monoclinic, and triclinic crystals have two, and are termed *biaxial*.

It follows that every section of an anisotropic crystal (except sections normal to an optic axis) has two directions of vibration, corresponding to different refractive indices, along which light entering at normal incidence is constrained to vibrate. In most cases these vibration directions are the same, or nearly the same, for all wavelengths; the refractive indices associated with them vary, of course, with the wavelength.

The maximum and minimum refractive indices of a crystal for a particular wavelength, together with, in the case of biaxial crystals, the index for light travelling along an optic axis, are known as *principal refractive indices*, and are important optical constants characteristic of the substance. In uniaxial crystals, one of these (ω) is the same for all directions of propagation, and the other (ε) is the index which differs most widely from it. In biaxial crystals, the maximum and minimum indices are denoted by γ and α respectively, whilst that for light travelling along an optic axis is denoted by β.

The equipment required for most optical crystallographic work is quite simple, and the set shown in figure 2 is adequate for all normal

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problems. The essential item, the polarizing microscope, is a compound microscope fitted with a rotating stage and two nicol prisms (or 'Polaroid' plates in some modern British and American models[1]). The lower nicol (*polarizer*) is fitted below the stage, and the upper one (*analyser*) at some position above the objective. When both nicols are in position and 'crossed,' cubic crystals can be distinguished immediately from anisotropic crystals, since the former remain as dark as the rest of the field in all positions, whilst the latter in most positions exhibit *polarization colours* (if white light is used) but 'extinguish' at intervals of 90° as the stage is rotated. The reasons for these phenomena are that isotropic material has no effect on the vibration direction of the light from the polarizer, but anisotropic crystals resolve this light into a 'fast' and a 'slow' beam, components of which interfere in the analyser. Only part of the spectrum emerges in phase, and so the light seen is coloured. As the stage is rotated, the vibration directions of the crystal become parallel to those of the nicols every 90°, and extinction results because at these positions the crystal does not affect the vibration direction of the light from the polarizer (see figure 1). Observations of the effect of compensators (crystal wedges and plates of known optic orientation and birefringence—see figure 2) on the polarization colour shown by a crystal section enable its 'fast' and 'slow' vibration directions to be found.

By illuminating a crystal between crossed nicols with a strongly convergent beam of light and bringing to a focus rays which have passed through the crystal in parallel directions, an *interference figure* is obtained. This consists in general of a pattern of polarization colours and bands of darkness. A study of the characteristic patterns given by certain sections of the crystal reveals whether it is uniaxial or biaxial, and in the latter case enables the angle between the optic axes to be measured. It is also an important means of determining the orientation of the principal vibration directions (that is, those associated with the principal indices) with respect to the external form of the crystal.

Refractive indices are determined with the polarizing microscope by making use of the fact that when a crystal is immersed in a liquid having the same index, the crystal/liquid boundary disappears. It is therefore only necessary to mount portions of the material in a succession of liquids of known index until one is found in which the crystal border is invisible. The search is facilitated by the fact that the greater the difference between the indices of crystal and liquid, the stronger is the relief in which the former appears, and also by observations of the so-called Becke line. The latter is a bright line of light which appears, under suitable conditions of illumination, just inside the medium of higher index, and (a more certain indication) which moves farther into that medium when the microscope tube is slightly raised. The two indices of a birefringent section may be

[1]Such microscopes are now being produced by Messrs. Cooke, Troughton, and Simms, and by the Spencer Lens Company. The advantages are that a wide aperture may be provided without undue expense, the construction of the microscope is simplified, and the maker is independent of the supply of Iceland spar of optical quality, which is not abundant.

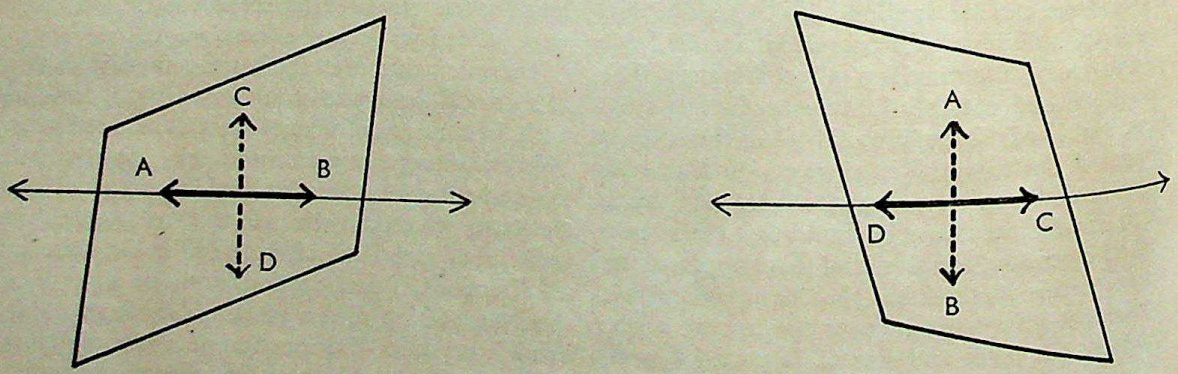

FIGURE 1 – *Isolation of the beams transmitted by a crystal section. In both positions shown the crystal would be 'in extinction' between crossed nicols. The long horizontal arrows represent the vibration direction of the light from the polarizer.*

(a) Vibration direction AB of crystal parallel to vibration direction of light from polarizer; no light vibrating parallel to CD is transmitted.

(b) Crystal turned through 90°. Vibration direction CD of crystal now parallel to vibration direction of light from polarizer; no light vibrating parallel to AB is transmitted.

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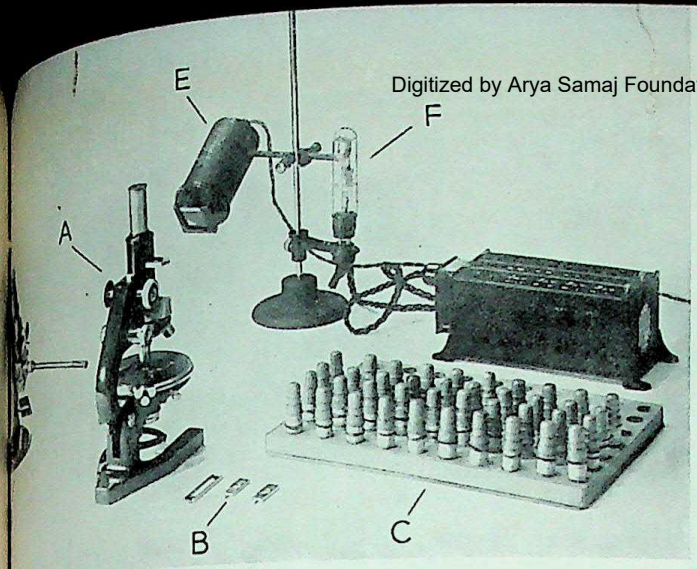
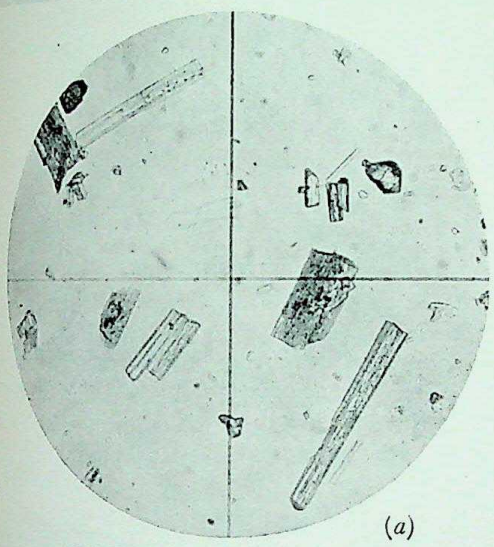
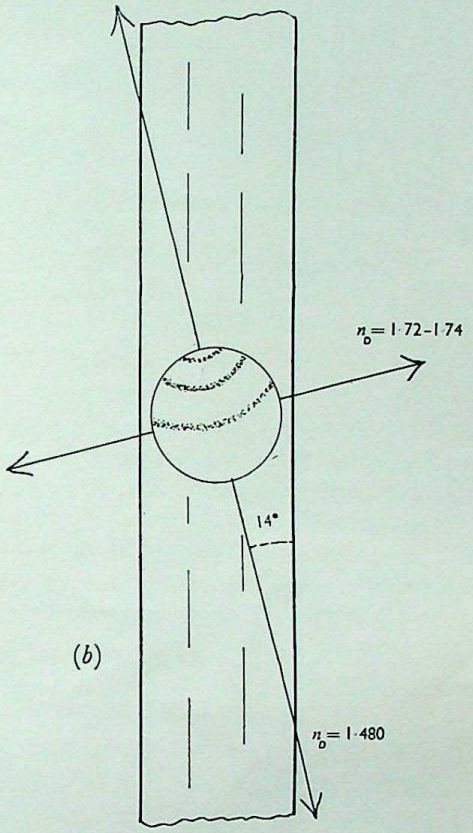


FIGURE 2 (left). *Equipment required for determining optical crystallographic properties.*
A = *Polarizing microscope.*
B = *Compensators (quartz wedge, $\frac{1}{4}$-wave mica plate, 1-wave gypsum plate).*
C = *Mounting liquids of known refractive index.*
D = *Abbé refractometer for checking values of C.*
E = *Source of white light.*
F = *Sodium lamp.*

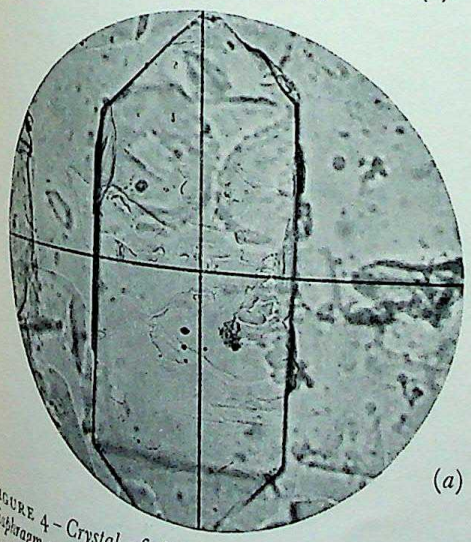


(*a*)



(*b*)

FIGURE 3 – *p-Nitrobromobenzene.*
Mounted in liquid of index 1·494 (*D*) (× 100) *in polarized light vibrating parallel to horizontal cross-hair. Crystals lying nearly parallel to this direction show weak relief, since the index for light vibrating along their length is near that of the liquid. (See (b).)*
Optical properties of section presented by crystals in (a).



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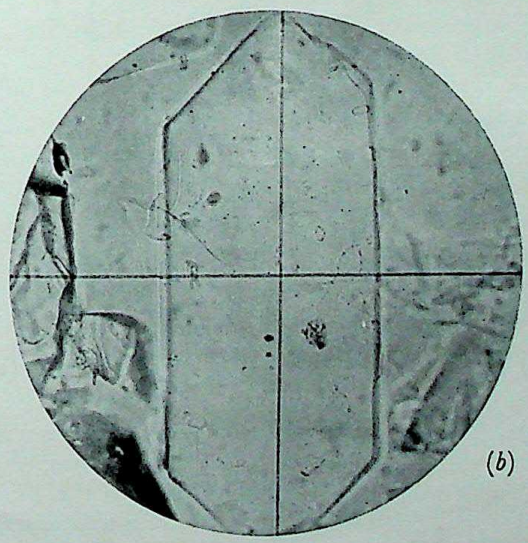

(*b*)

FIGURE 4 – *Crystal of $NH_4H_2PO_4$ mounted in liquid of index* 1·531 (*D*) *in polarized light* (× 100). *Substage diaphragm nearly closed.*
(a) Light vibrating vertically, parallel to the ε (1·479, *D*) *vibration direction. Note strong relief.*
(b) Light vibrating horizontally, parallel to the ω (1·525, *D*) *vibration direction. Crystal and liquid are nearly matched.*
In both cases note Becke line just outside border of crystal, indicating $n_{liquid} > n_{crystal}$.

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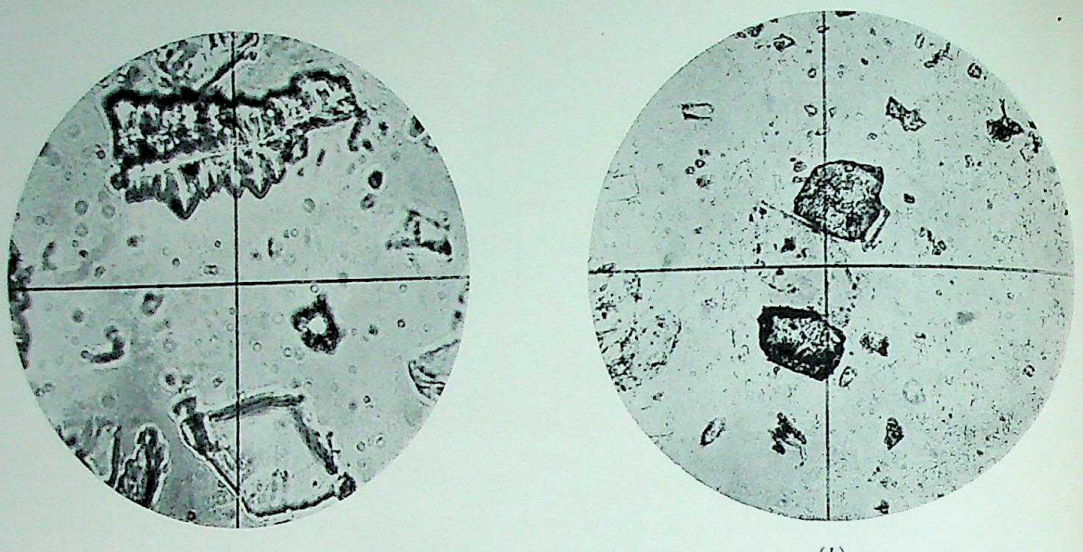
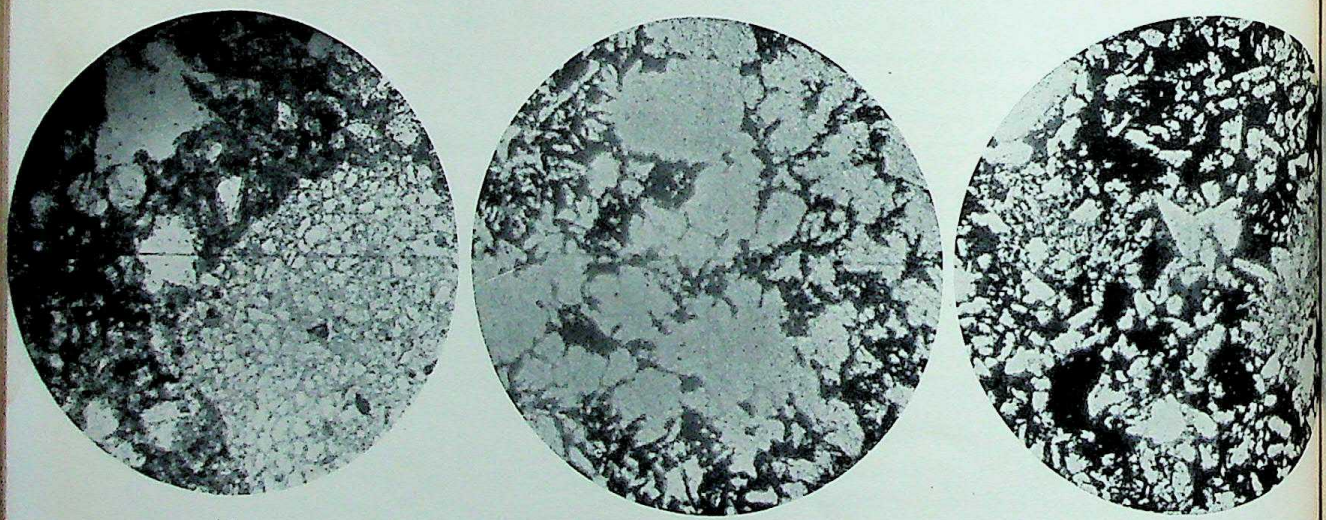


(*a*) (*b*)

FIGURE 5 – *Distinction between salt mixtures having the same ions.*

(*a*) $PbCl_2 + Ba(NO_3)_2$ *in liquid of index* 1·633 (× 480). *Substage diaphragm nearly closed. Dendritic crystal of* $PbCl_2$ (*birefringent,* $n_D = 2{\cdot}199$–$2{\cdot}260$) *in upper half of figure shows Becke lines inside crystal border. Large crystal of* $Ba(NO_3)_2$ (*isotropic,* $n_D = 1{\cdot}571$) *in lower half of figure shows Becke line outside crystal border.*

(*b*) $Pb(NO_3)_2 + BaCl_2.2H_2O$ *in same liquid* (× 100). *In centre of figure are two large crystals of* $Pb(NO_3)_2$ (*isotropic,* $n_D = 1{\cdot}7815$) *in strong relief, with crystal of* $BaCl_2.2H_2O$ (*birefringent,* $n_D = 1{\cdot}635$–$1{\cdot}660$) *between. The latter shows in weak relief, since* $n_{liquid} \approx n_{crystal}$.



(*a*) (*b*) (*c*)

FIGURE 6 – *Thin sections of silica brick* (× 50).

(*a*) *Soft-burned brick before use. Light area (lower right) is ganister fragment consisting of unaltered quartz. Remainder largely interstitial material consisting of unaltered quartz grains, with cristobalite and glass.*

(*b*) *After use as roof brick in open-hearth furnace. Inner zone, consisting of isotropic cristobalite (white grains in figure) and magnetite (dark ingredient) from furnace charge.*

(*c*) *Ditto, tridymite zone. Tridymite (white in figure) in typical prisms and 'arrowhead' twins, one of which is seen just above the centre of the figure.*

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separately compared in this way with that of the liquid by using polarized light and isolating the two beams as explained in figure 1.

Figure 4 illustrates the application of this method to ammonium dihydrogen phosphate, a uniaxial substance which habitually crystallizes in square prisms with pyramidal ends. These crystals lie on their sides, and in this position they present both of the principal indices, ε being that for light vibrating along the length of the prism, and ω that for the transverse direction.

In such cases the determination of the principal indices is a simple matter. It frequently happens, however, especially with crystals of low symmetry, that the most prominent faces, which determine how the crystals lie on the slide, are parallel to none of the principal vibration directions, and so the indices shown have intermediate values. Simple methods are available for determining the principal indices of such crystals, and also of crystal grains and fragments possessing no characteristic external form which adopt random positions on the slide, but space does not permit of their being described here. It should be said, however, that it is not always necessary to determine the principal indices of a substance in order to identify it. Figure 3 illustrates a case in point. *p*-Nitrobromobenzene habitually crystallizes as shown in (*a*), and nearly all the crystals lie so as to present the optical characters shown in (*b*), which gives the inclination of the vibration directions to the long axis of the crystal, the refractive indices (neither of them a principal one), and, in the central circle, the interference figure. Provided that the substance does not adopt some radically different habit, this combination of optical properties can be used to identify it.

The following examples are only a few of the very many that could be quoted to illustrate the value of the optical method, but they serve to show something of the range of problems covered.

The qualitative chemical analysis of a mixture of salts reveals merely what ions are present. For example, suppose that barium, lead, nitrate, and chloride ions are found. Does the mixture consist of $PbCl_2$ and $Ba(NO_3)_2$, or of $Pb(NO_3)_2$ and $BaCl_2.2H_2O$, or of some other possible variation? A knowledge of their refractive indices and of the fact that the two nitrates are isotropic enables a decision to be reached in a matter of minutes, merely by mounting the mixture in a liquid having an index intermediate between the extreme values shown by the salts and observing the Becke line and the behaviour between crossed nicols (see figure 5).

Some years ago, the author had occasion to examine some specimens of potassium mercuric iodide and ammonium dihydrogen phosphate, the purity of which was in doubt [2]. Under the microscope the former was seen to contain colourless isotropic crystals with a refractive index slightly greater than 1·66. This showed that the impurity was potassium iodide, which is cubic and has an index of 1·67. Associated with the uniaxial phosphate were found fragments which did not show the ω value of this salt, and gave biaxial interference figures. This suggested that the impurity might be the biaxial diammonium salt, and this was confirmed by a determination of the β index. In neither of these cases could the impurity have been identified by chemical analysis.

Numerous examples of the use of the polarizing microscope in organic chemistry have been quoted by Benedict [3]. For instance, in studying the preparation of certain amino acids he was able to save much time by using optical methods of identification (based on data previously obtained by Keenan; see below), particularly in view of the fact that the acids had indefinite melting-points and could not be characterized by this property. A drop of the reaction mixture could be quickly examined with the microscope to see whether in fact it contained the required product, and so no time was wasted in working up the products of unsuccessful runs. Side reactions were also investigated by the same means.

Bennett and his co-workers have used the method as a means of differentiating between organic stereoisomers, a particularly interesting example being the isomeric trithioacetaldehydes [4]. Two isomers only are required by stereoisomeric theory, and an alleged third isomer was found under the polarizing microscope to be a eutectic mixture of these two.

With the objects of demonstrating the value of the optical method in organic chemistry and of adding to the body of published data, a large number of optical crystallographic studies of series of related compounds have been undertaken during the past thirty years, mainly in America. Among the most prolific workers in this field are G. L. Keenan and W. M. D. Bryant. Keenan's studies have included sugars, amino acids, and substances listed in the U. S. Pharmacopoeia [5], while Bryant has studied derivatives of alcohols, aldehydes, and aliphatic acids [6], among many other compounds. It has been found with very

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few exceptions that compounds in the same series can readily be distinguished from one another by determining their refractive indices or by other simple optical tests.

The optical method has played a valuable, and in some cases essential, part as a means of identifying the solid phases in phase-equilibrium studies. Thus, in investigations of high-temperature silicate systems, such as have been in progress for some years in America and at the Building Research Station in Britain, ordinary methods of thermal analysis are of little use, since equilibrium is attained so sluggishly. The method mainly adopted is to quench equilibrium mixtures of the components and examine the resulting solid under the polarizing microscope. Any liquid present in the original equilibrium mixture quenches to a glass, which can be recognized by its isotropic character. Crystalline solid phases are identified by their characteristic optical properties. In this way the thermal diagram may be built up. A knowledge of the equilibria in systems of this type is of fundamental importance in petrological research and in the study of cement, slags, and refractories. The classical example, which sheds much light on the constitution of Portland cement, is the system $CaO–Al_2O_3–SiO_2$ studied by Rankin and Wright [7], and in the same connection the important quaternary system $CaO–2CaO$, $SiO_2–5CaO$, $3Al_2O_3–4CaO$, Al_2O_3, Fe_2O_3 has been studied by Lea and Parker [8].

Optical methods play an important part in the study of refractories as such, and a good example is afforded by the changes undergone by silica bricks in the open-hearth furnace. In a soft-burned brick before use the silica is present mainly as quartz (figure 6(*a*)), distinguishable from the other polymorphic modifications of silica by its marked double refraction. During use the silica in the inner and hottest zone of the brick becomes converted to cristobalite (figure 6(*b*)), which is isotropic and thus immediately identifiable between crossed nicols. Adjoining this zone is a somewhat cooler one, where the silica has been converted to tridymite (figure 6(*c*)), which has a low double refraction, and also crystallizes in characteristic shapes. The widths of these zones show the temperature gradient to which the brick has been subjected, and this is an important factor in the life of the furnace lining.

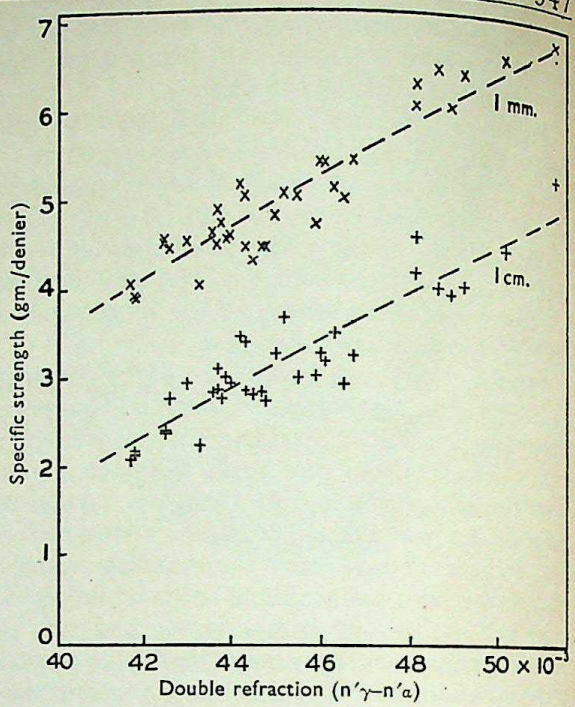

FIGURE 7 – *Relation between double refraction and strength of cotton fibres* (1 *mm. and* 1 *cm. lengths*).
(*n′γ and n′α are the indices for light vibrating respectively along and across the fibre.*)
(*Reproduced by permission of the British Cotton Industries Research Association.*)

Numerous investigations on the relation between the optical properties, and in particular the refractive indices, of fibres and their other physical properties have been undertaken. Thus it has been found by the British Cotton Industry Research Association [9] that there is a high degree of correlation between the birefringence of cotton fibres and their strength (see figure 7).

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The principles of chromatography

A. J. P. MARTIN

Chromatography is a method of chemical analysis founded on differential adsorption in a counter-current process. Although the basic procedure of the method was very firmly established by the Polish botanist Tswett more than thirty years ago, it is only during the past decade that chemists have recognized its great value and made effective use of it. Dr Martin here describes the principal features of the practical technique, and discusses some theoretical considerations of importance in the use of the method.

Chromatography has been so widely used in the last fifteen years that to give an adequate account of its achievements would be a problem as difficult as to give an account of the achievements of distillation. Since its first use in the form of capillary analysis by Schönbein (1861) and its later development by Tswett (1906), chromatography is already quite indispensable in many fields, and may be expected to become so in any field where the separation of very similar substances is required. Although chromatography has a remarkably wide field of application, the method rests on principles which can be described without reference to specific examples. In the following discussion my illustrations are confined largely to partition chromatography with which I have myself been associated, not because it is more important but because it is less familiar.

Chromatography is a counter-current, or column, process. It bears the same relationship to simple methods of separation by adsorption, in which the adsorbent is merely stirred with the solution, as distillation with a fractionating column does to simple distillation. The analogy with the fractionating column is indeed close. Just as distillation with a fractionating column is equivalent to thousands of separate distillations, so chromatography, with its ordered movement of liquid relative to the adsorbent with which it is continuously equilibrating, is equivalent to a repeated stirring up with adsorbent and filtering. In many cases this differential rate of movement permits the separation, with only infinitesimal contamination, of substances whose adsorption is so similar that no useful separation could be obtained by simply stirring with the adsorbent.

The ideal chromatogram consists of a tube containing a column of porous adsorbent through which the solution is percolating. The proportion of liquid to solid at all points is constant, and the flow of liquid is uniform. Suppose now that a solution of some suitable solute runs into the column in place of the pure solvent. If in any thin cross-section of the column the fraction of the solute in the solvent is α, then $(1-\alpha)$ is adsorbed on the solid. Equilibrium between solid and liquid is, in this ideal case, instantaneous, and no diffusion occurs. It is obvious, since a fraction α is moving with the speed of the liquid and a fraction $(1-\alpha)$ is stationary, that the net rate of movement of the solute is α times the rate of movement of the liquid. *This ratio of the rate of movement of the solute to the rate of movement of the solvent* is called the R_F value. This ideal case is shown in figure 1; it has been interpreted by Wilson [1].

In fact, of course, equilibrium is not attained instantaneously. The solute has to move from liquid to solid and *vice versa*, and this has important practical consequences. For rapid equilibrium the distance over which diffusion must carry the solute must be made as small as possible. It is therefore nearly always a mistake not to use a finely ground adsorbent. Figure 2 shows how the band of solute loses its sharp edges when attainment of equilibrium is not instantaneous. The band approximates more and more closely to the 'error curve' shape as it progresses down the column [2].

So far it has been assumed that the ratio of the concentration of solute in the liquid and in the adsorbent at equilibrium is a constant, i.e. a linear adsorption isotherm has been assumed. This is usually not the case. Generally the proportion of solute in the liquid phase rises as the concentration is increased (Freundlich or Langmuir adsorption isotherm). Figures 3 and 4 show the resulting shapes of the bands. The R_F value rises with the concentration; consequently the front of the band moves faster than the back, and the band broadens. The front stays relatively sharp (figure 4), since the layer of diminishing

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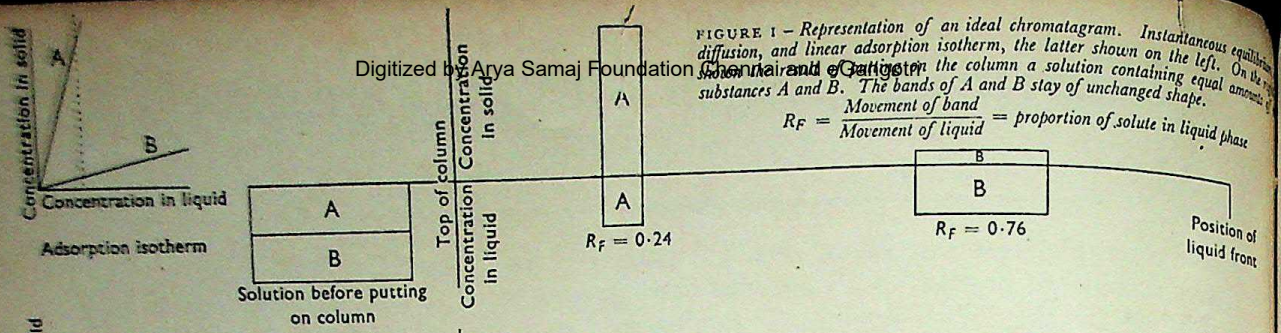

FIGURE 1 – *Representation of an ideal chromatagram. Instantaneous equilibrium, no diffusion, and linear adsorption isotherm, the latter shown on the left. On the top of the column a solution containing equal amounts of substances A and B. The bands of A and B stay of unchanged shape.*

$$R_F = \frac{\text{Movement of band}}{\text{Movement of liquid}} = \text{proportion of solute in liquid phase}$$

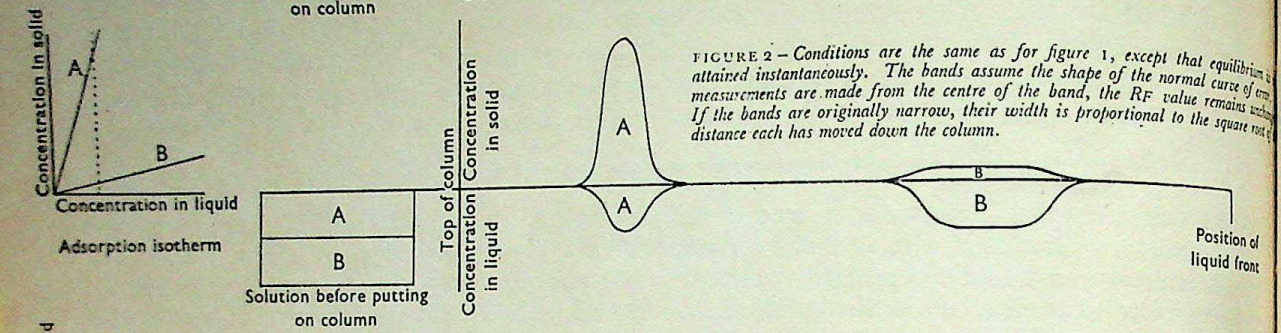

FIGURE 2 – *Conditions are the same as for figure 1, except that equilibrium is attained instantaneously. The bands assume the shape of the normal curve of error. If measurements are made from the centre of the band, the R_F value remains unchanged. If the bands are originally narrow, their width is proportional to the square root of the distance each has moved down the column.*

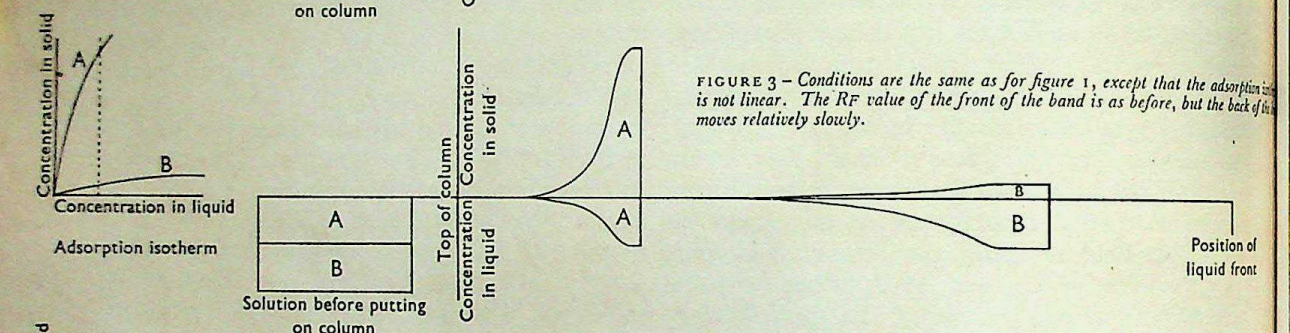

FIGURE 3 – *Conditions are the same as for figure 1, except that the adsorption isotherm is not linear. The R_F value of the front of the band is as before, but the back of the band moves relatively slowly.*

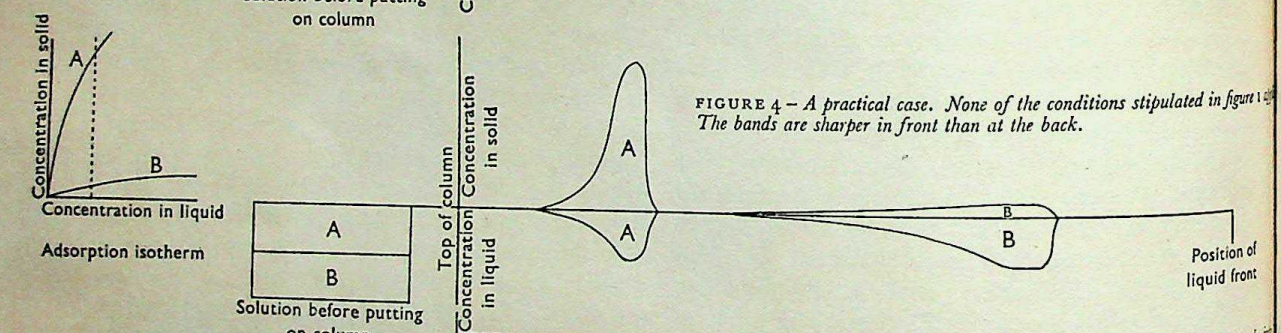

FIGURE 4 – *A practical case. None of the conditions stipulated in figure 1 apply. The bands are sharper in front than at the back.*

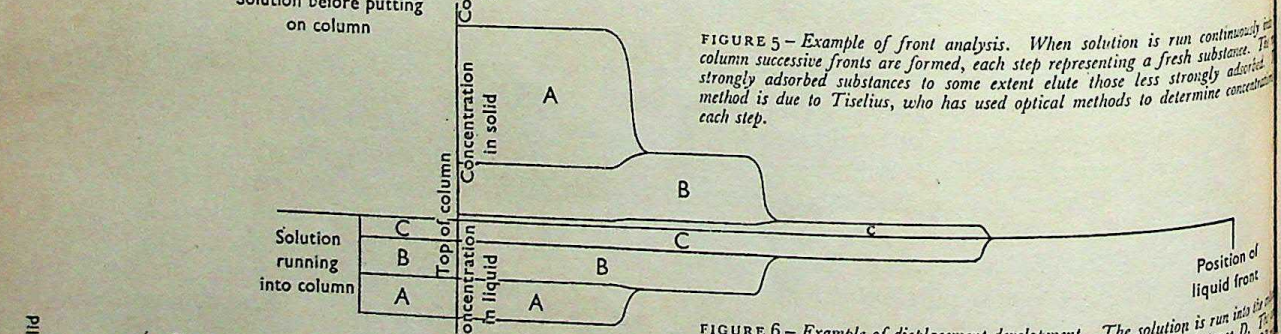

FIGURE 5 – *Example of front analysis. When solution is run continuously into the column successive fronts are formed, each step representing a fresh substance. The more strongly adsorbed substances to some extent elute those less strongly adsorbed. The method is due to Tiselius, who has used optical methods to determine concentrations in each step.*

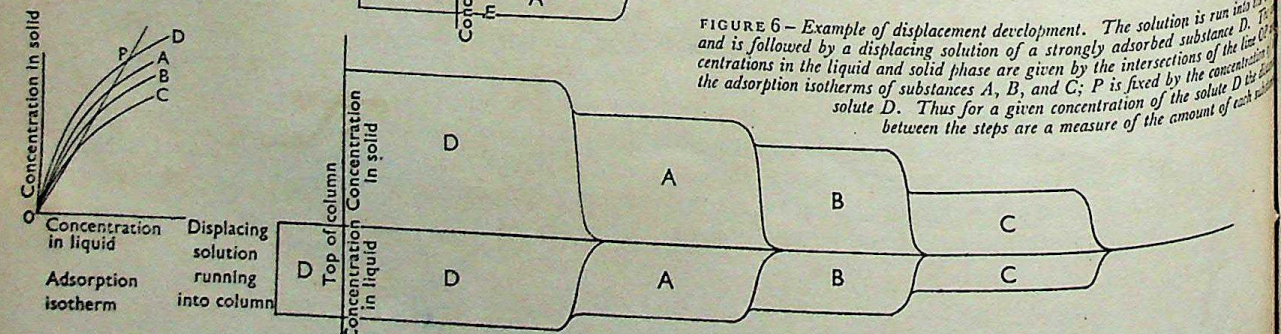

FIGURE 6 – *Example of displacement development. The solution is run into the column and is followed by a displacing solution of a strongly adsorbed substance D. The concentrations in the liquid and solid phase are given by the intersections of the line OP with the adsorption isotherms of substances A, B, and C; P is fixed by the concentration of the solute D. Thus for a given concentration of the solute D the distances between the steps are a measure of the amount of each substance.*

FIGURES 1–6 – *Typical examples of chromatographic adsorption. For further explanation see text.*

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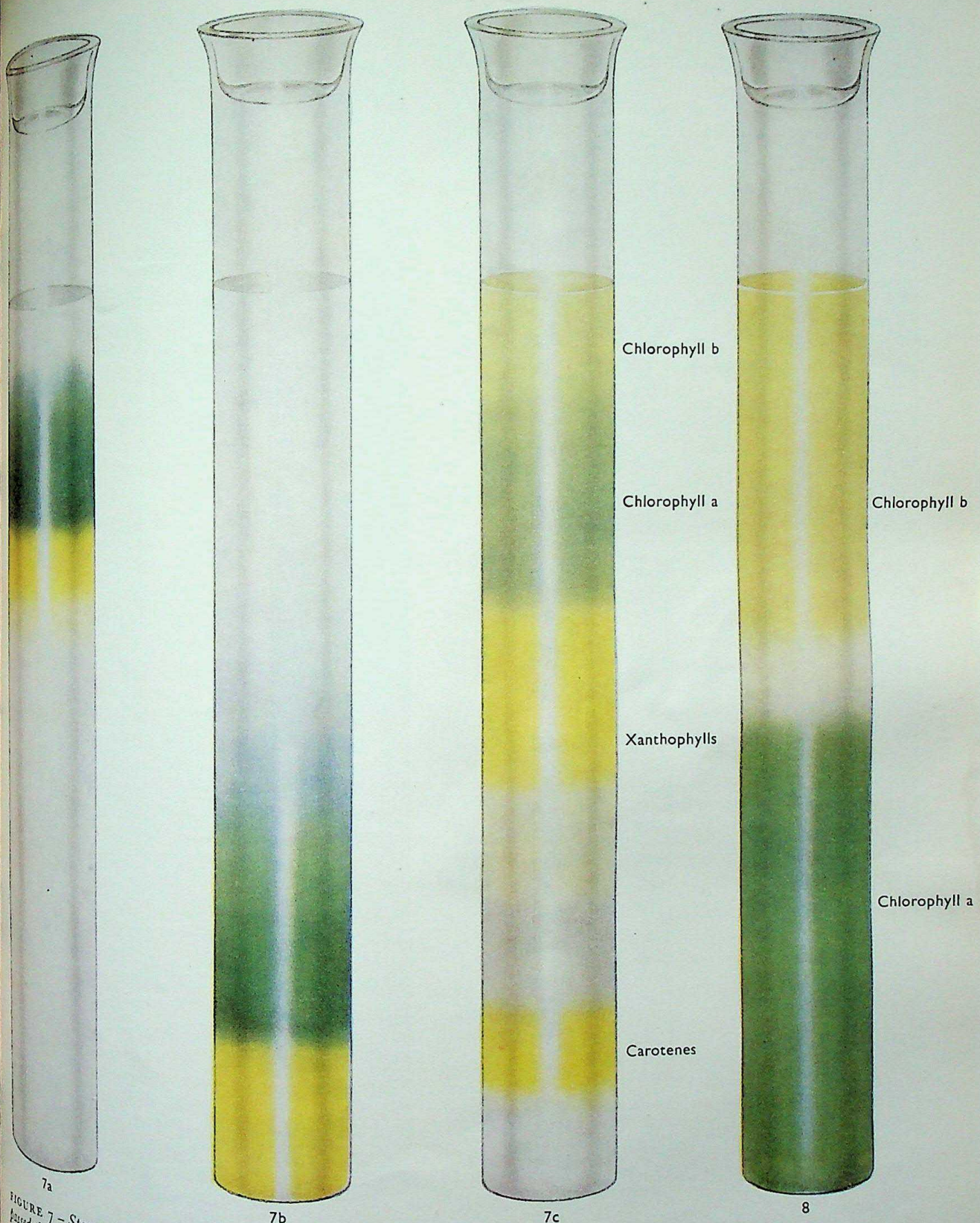

FIGURE 7 – *Stages in the development of the adsorption chromatogram formed when an extract of grass in cyclohexane is passed through a column of starch.*
(a) *Start of development. Colourless substances are displacing chlorophyll and carotene.* $R_F = 1$, *so no resolution can be seen.*
(b) *Most of the colourless material has been adsorbed, and the carotene band is showing in front of the chlorophyll.* $R_F < 1$.
(c) *The coloured bands have been separated, the pigments extracted again into cyclohexane, and the resulting solution passed through a new column. Displacing substances have been left on the old column. Elution development (page 27) shows bands of chlorophylls, xanthophylls, and carotenes.*

FIGURE 8 – *The same as 7(c), except that for development cyclohexane has been replaced by benzene.*

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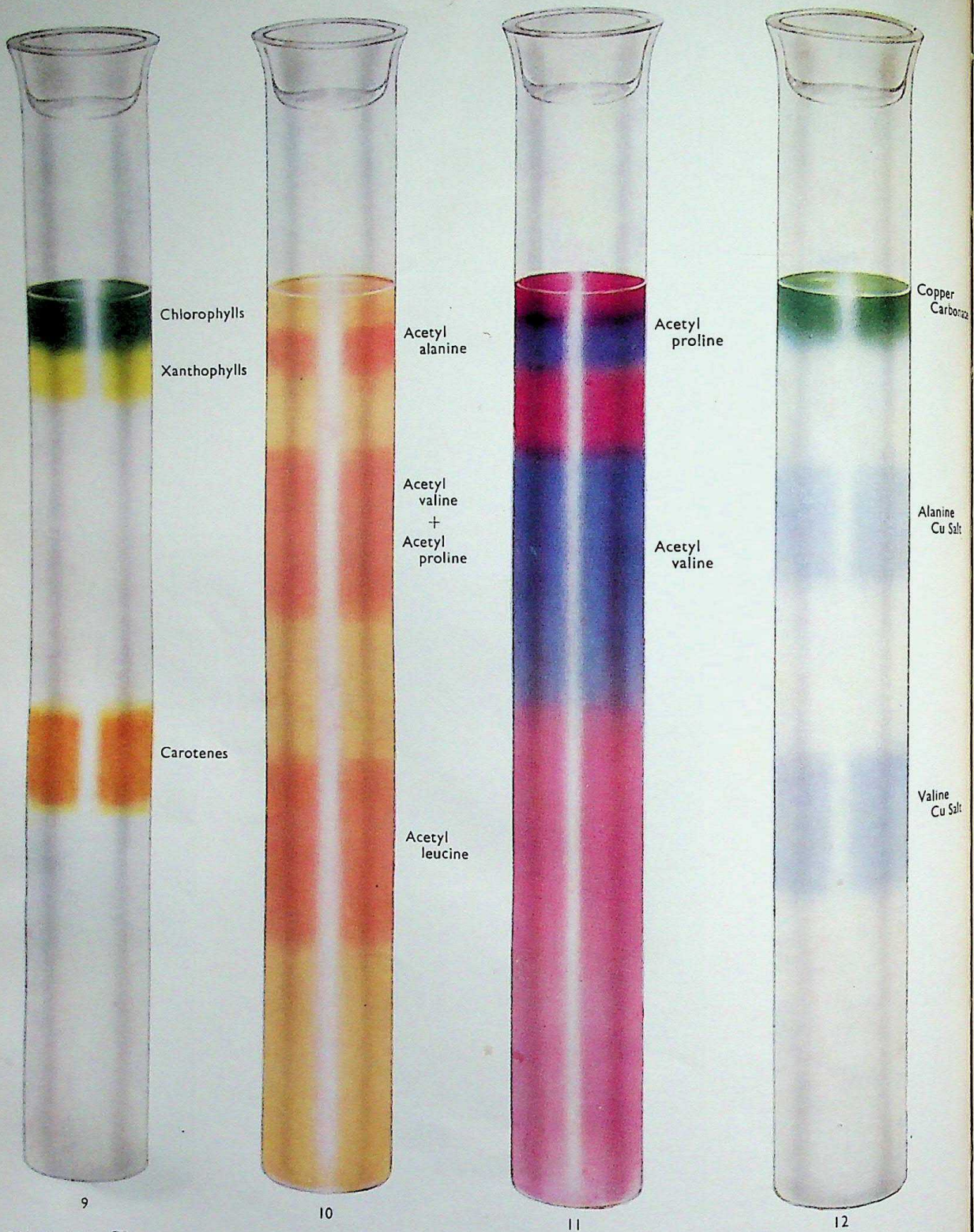

FIGURE 9 – *The same solution as that used for producing the chromatograms shown in figure 7 passed through a column of magnesium oxide. Chlorophylls are strongly retained. Elution development has revealed bands of xanthophylls and carotenes.*

FIGURE 10 – *Partition chromatogram showing separation of acetyl alanine, acetyl valine, acetyl proline, and acetyl leucine on a silica gel column. The silica gel was prepared with water containing methyl orange as indicator, and the position of the acetyl amino acids is shown by the red colour. The solvent is chloroform containing 1% of butanol.*

FIGURE 11 – *Separation of acetyl proline and acetyl valine on a column of silica gel, using a special indicator. The solvent is cyclohexane. Using columns of the type shown in figures 10 and 11, it is possible to estimate quantitatively the amount of alanine, leucine and isoleucine, phenyl alanine, tyrosine, and methionine contained in the hydrolysate of 20 mg. of protein.*

FIGURE 12 – *Separation of the copper salts of alanine and valine on a column of silica gel. The partition chromatogram has been developed with a mixture of chloroform and butanol.*

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Partition chromatograms on strips of filter paper. A drop of a solution of amino acids is placed near the top of a strip of filter paper. The strip is hung from a glass trough in an atmosphere saturated with water and solvent. Solvent, also saturated with water, siphons over and down the strip. The strip is dried and sprayed with a solution of ninhydrin, and heated. The reagent reveals the position of the amino acids as coloured patches.

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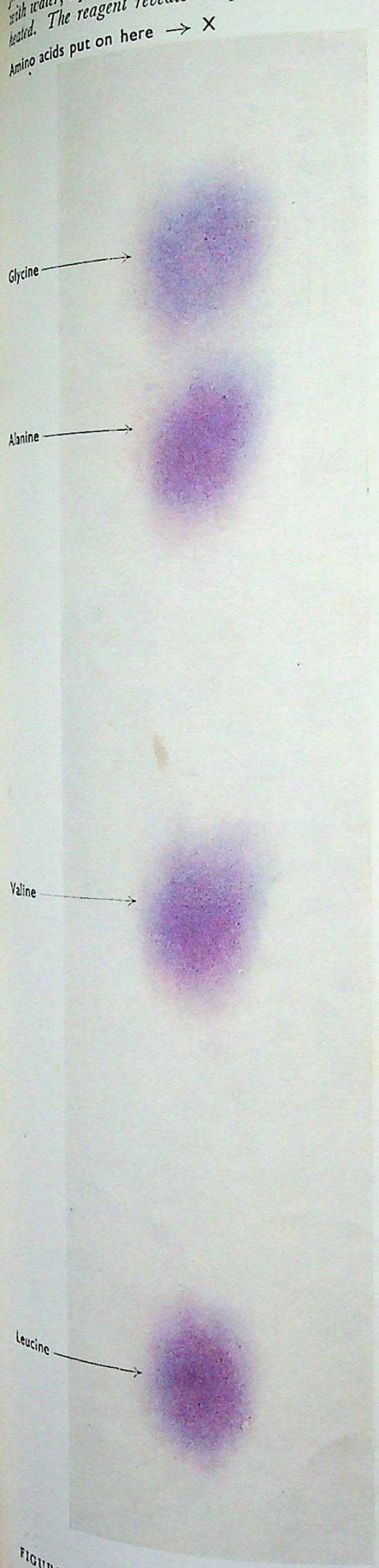

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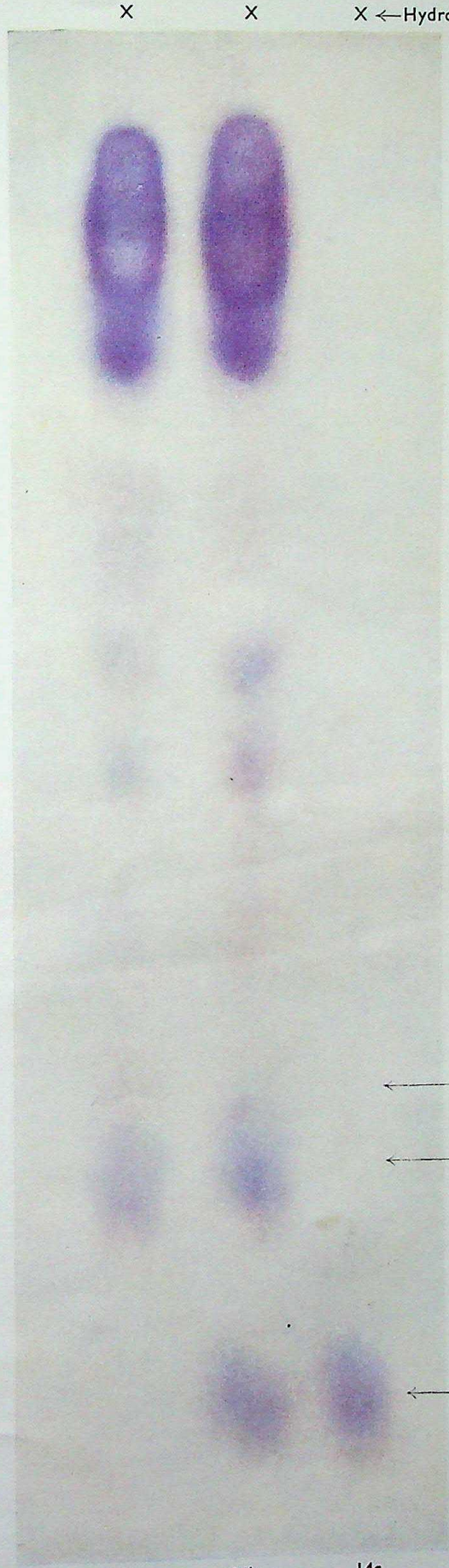

14a 14b 14c

FIGURE 13 – *Separation of glycine, alanine, valine, and leucine, using butanol as solvent.*

FIGURE 14 – *Chromatogram obtained with a hydrolysate of spinal cord, (a) without and (b) with addition of synthetic norleucine. In a control experiment (c)* norleucine *alone is used. The solvent is benzyl alcohol. These chromatograms show clearly that, contrary to claims made in the past,* norleucine *is not contained in the spinal cord.*

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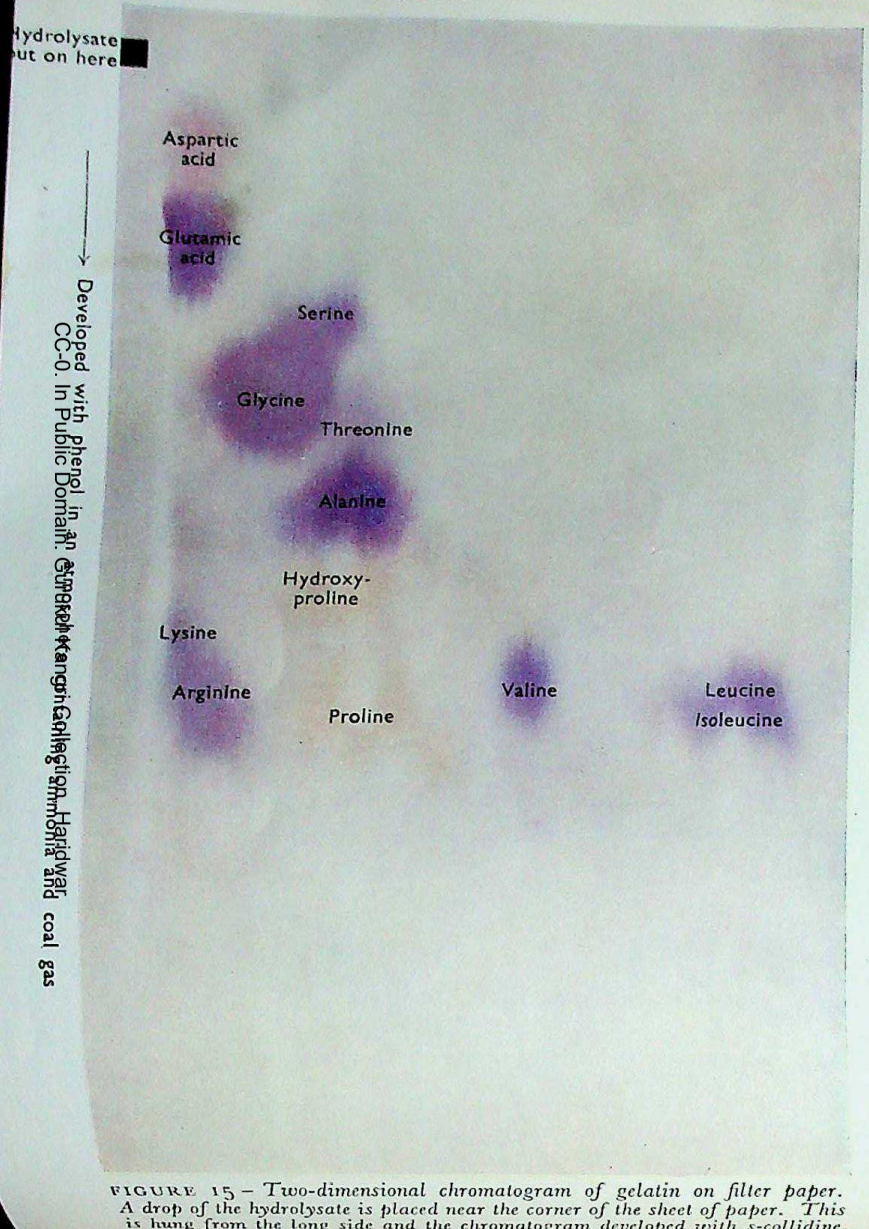

FIGURE 15 – *Two-dimensional chromatogram of gelatin on filter paper. A drop of the hydrolysate is placed near the corner of the sheet of paper. This is hung from the long side and the chromatogram developed with s-collidine. The paper is dried, hung from the short side, and the chromatogram developed with phenol. It is dried again, sprayed with ninhydrin, and heated.*

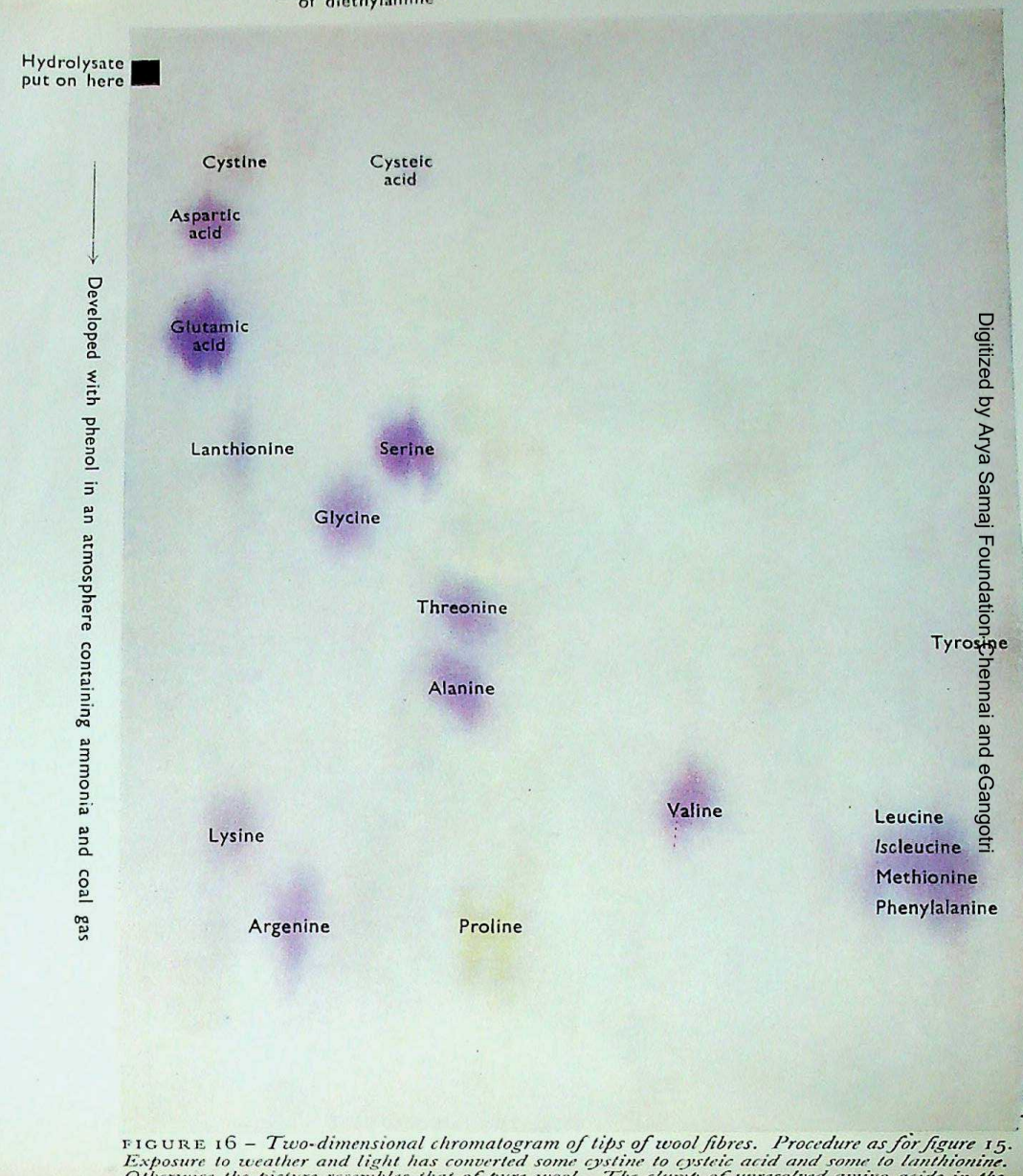

FIGURE 16 – *Two-dimensional chromatogram of tips of wool fibres. Procedure as for figure 15. Exposure to weather and light has converted some cystine to cysteic acid and some to lanthionine. Otherwise the picture resembles that of pure wool. The clump of unresolved amino acids in the right-hand bottom corner can be separated if benzyl alcohol and butanol are used in place of collidine and phenol, but then the other spots are crowded together.*

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concentration at the front of the band, caused by diffusion and slow attainment of equilibrium, is continuously overrun by the faster-moving, more concentrated zone behind. The case illustrated in figure 3 has been interpreted by De Vault [3] and Weiss [4].

There is, however, a further complication. The adsorption of one substance may greatly modify the adsorption of another. This is particularly the case when the adsorption isotherms are of the Freundlich or Langmuir type. Figure 5 shows the result of running a relatively large volume of a solution of three substances down a column without 'developing' the chromatogram, i.e. further separating the bands, with pure solvent. If the adsorption of one were not influenced by another, the concentration in the steps would be the same as in the original solution.

If a mixed solution running into the column, as in figure 5, is replaced by a solution of another and more strongly adsorbed substance (*D*), the state shown in figure 6 soon occurs, since each substance 'elutes' or washes off the substance in front of it. In the absence of interaction, elution development would be superposed on a background of *D*. This is interesting as representing a steady state, the bands of *A*, *B*, and *C* moving down the column with unchanging shape.

METHODS OF CHROMATOGRAPHY

Figures 4, 5, and 6 represent three different ways in which chromatograms can be employed. The method of figure 4 (elution development) is the most familiar in the laboratory. After adequate development the column is cut up and the adsorbent extracted with a suitable eluting solvent, or development is continued until the bands run separately from the bottom of the column in the solvent. The latter method of working has been misleadingly named 'liquid chromatography.' In using this method a linear adsorption isotherm is desirable, as otherwise each band tends to tail more or less into the succeeding band.

The method of figure 5, often not recognized as chromatography at all, is extremely widely used in industry for water softening, recovery of valuable ions in industrial wastes, and for solvent recovery from air or other gases. It is remarkable that this solvent recovery process seems to be the only use at present of gas as the mobile fluid in chromatography, though there appears to be no reason why it should not be a valuable method for analytical purposes. Recently Tiselius has applied this method to analysis. He has developed 'front analysis,' as he calls it, into a most powerful tool for dealing with intractable mixtures such as amino acids and peptides. By applying the optical techniques developed for electrophoresis and ultracentrifugal investigations to the liquids issuing from a chromatogram, a peak is obtained wherever the concentration changes. Thus figure 5 would show three peaks.

Tiselius has also developed the 'displacement development' method (figure 6), recording the concentration of the effluent from the column with an automatic interferometer. A record is obtained of a series of steps, the length of each of which is a measure of the amount of each substance present, while the height is determined by the adsorption isotherm.

In distinction to the elution development method, a non-linear adsorption isotherm is an advantage with the last two methods, since the fronts remain sharper and are easier to observe.

ADSORBENTS AND SOLVENTS USED

Alumina and Other Metallic Oxides. The choice of adsorbent and solvent has hitherto been almost entirely empirical. The adsorbent most commonly used in laboratory work is alumina, with non-polar solvents such as petrol. Various metallic oxides and salts behave more or less similarly. The method of preparation of the adsorbent is as important as its chemical composition. Polar and polarizable groups in the solute are the chief determinants of adsorption behaviour with this class of adsorbent. Similarly, elution is caused by polar or polarizable solvents. If a solvent forms hydrogen bonds, it is usually a good eluting agent. These adsorbents differ widely in strength but little in selectivity; the order of bands of different substances is seldom different on different adsorbents of this class.

Carbon. Active carbon, though long used as an adsorbent for decolorizing solutions and for solvent recovery, has only recently been used in analytical chromatography. The adsorption isotherms on carbon are usually far from linear, and it is thus most suitable for 'front analysis' and 'displacement development' (see above). It seems to have several or perhaps many different kinds of adsorbing sites, and carbons with widely different adsorptive selectivity can be produced by different methods of activation. In general it may be said that fatty chains, and particularly aromatic rings, determine adsorption on carbon, while polar groupings are less important. Thus adsorption of amino acids, for example, takes

FIGURE 15 – *Two-dimensional chromatogram of tips of wool fibres. Procedure as for figure 15. Exposure to weather and light has converted some cystine to cystéic acid and some to lanthionine. Otherwise the picture resembles that of pure wool. The change of unresolved cystine acids in the original diagram to two spots can be interpreted as due to differential destruction of lanthionine and cystéic acid.*

FIGURE 16 – *Two-dimensional chromatogram of gelatin on filter paper. A drop of the hydrolysate is placed near the corner of the sheet of paper. This is hung from the long side and the chromatogram developed with s-collidine. The paper is dried, hung from the short side, and the chromatogram developed with phenol saturated with water. The spots are developed with ninhydrin and heated.*

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place from aqueous solution, and they can be eluted by phenol or ephedrine. Pre-treatment of the carbon is usually necessary to prevent irreversible adsorption and catalytic oxidation.

Ion Exchangers. Ion-exchange materials have long been used for water softening but have only recently been used to any great extent in analytical chromatography. They are essentially large insoluble acids or bases which form insoluble salts. The first of such substances to be employed, the zeolites, were unstable in acid solution, and were used to exchange Na^+ for other cations. Adams and Holmes showed that certain synthetic resins possess exchange properties. Sulphonated coal or resins containing sulphonic acid groups are now in use, and will exchange H^+ ions for other ions. There are similarly basic resins which will exchange anions. With these adsorbents the adsorbed molecules are held by electrostatic forces, and it is charge, not molecular structure, that chiefly determines adsorption. Elution is effected by acid, alkaline, or salt solutions.

PARTITION CHROMATOGRAMS

Martin and Synge [2] have introduced silica gel into chromatographic analysis. Dry precipitated silica will take up about half its weight of water without appearing to become wet. A chromatogram can be made with such saturated silica and any solvent not completely miscible with water. With a suitable choice of solvent no adsorption occurs on the silica itself, and the formation of the chromatogram depends entirely upon partition between solvent and water. A typical column is illustrated in figure 10. In such a partition chromatogram the calculated R_F value, derived from the partition coefficient and amounts of water and immiscible solvent, agrees with the observed value.

Other liquids may be used in place of water, and starch, cellulose, or other substances in place of silica. Cellulose in the form of filter paper is a particularly useful material. Using narrow strips of paper it is possible to produce chromatograms analogous to those produced when ordinary columns of material are used. The use of paper strips is illustrated in figures 13 and 14. By using squares of paper (figures 15 and 16) a twofold separation can be effected. The solution to be analysed is applied at one corner of the square and a chromatogram is formed in the same way as when a strip of paper is used. To avoid evaporation the paper must be placed in an enclosure the atmosphere of which is saturated with respect to the solvents used. The paper is then dried, turned through 90 degrees, and the process repeated. A new solvent is used and each 'band' of the initial chromatogram is made the starting-point of another 'strip' chromatogram. The final result is to spread the constituents of the mixture over the whole sheet of paper instead of confining them to the original strip.

The partition chromatogram is highly selective, since solvents may be chosen which associate with particular groupings in the solute. A close analogy can be drawn between the effect of association on the partition coefficient between two liquids and between liquid and vapour. In the latter case association may give rise to azeotropic mixtures.

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The Chemical Society of London

After a delay of six years occasioned by the war, the Chemical Society (of London) will celebrate the centenary of its foundation on 15th, 16th, and 17th July, 1947. Outstanding among the several important events which will mark the occasion will be the delivery of the Faraday Lecture by Sir Robert Robinson, a past President of the Chemical Society and now President of the Royal Society. The centenary celebrations will be followed by the Eleventh International Congress of Pure and Applied Chemistry, also to be held in London. Many distinguished overseas delegates have been invited to attend, and if all are able to do so there will be seen in London next July perhaps the greatest international gathering of chemists ever to have taken place.

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Organosilicon compounds and their industrial development

D. V. N. HARDY

Organosilicon compounds have been investigated for over eighty years, an outstanding contribution having been made by Professor F. S. Kipping, F.R.S., but it was only towards the end of the recent war that mention began to be made of commercial developments. Owing largely to difficulties in obtaining the new materials, first-hand information has hitherto been very scanty, and the precise nature and importance of the substances have been obscured by a secrecy necessitated by both military and commercial considerations.

Although initially studied by a sequence of investigators on the Continent, notably Friedel and his students Crafts and Ladenburg, the chemistry of organosilicon compounds will always be associated with Professor F. S. Kipping and his school of research workers at University College, Nottingham. Starting in 1899, Kipping diligently pursued the subject for close on forty years, and contributed over fifty papers to the *Journal of the Chemical Society*. The work was arduous and beset with experimental difficulty, not the least being a remarkable tendency of the compounds to form amorphous, glue-like products, but with great patience Kipping went on to collect an invaluable mass of precise and detailed information, the accuracy of which has occasionally been challenged but always upheld.

Academic study of organosilicon compounds progressed along classical lines. It consisted chiefly in the preparation and characterization of the various compounds and in the determination of their chemical properties, with theoretical interest focused mainly upon the degree of similarity between organosilicon compounds and their carbon analogues. This similarity proved to be slight. In its ability to combine with itself and with other elements, silicon cannot approach the versatility of carbon, and the facile, subtle variety of organic reactions is not encountered in organosilicon chemistry. Of paramount importance among silicon compounds is the remarkable tendency to form large molecules containing chains, rings, or networks of alternating oxygen and silicon atoms. Silicic acid and the polysilicates are built on this plan, and so are many oxygenated organosilicon compounds.

The methods for preparing organosilicon compounds are few, and consist principally of treating a silicon halide or an alkyl silicate with an organometallic compound or its equivalent. Friedel and Crafts [1] used silicon tetrachloride and zinc alkyls:

$$SiCl_4 + 2Zn(C_2H_5)_2 \longrightarrow Si(C_2H_5)_4 + 2ZnCl_2$$

and Ladenburg [2] showed not only that ethyl orthosilicate may be employed in place of silicon tetrachloride but that arylchlorosilanes can be prepared with mercury diaryls:

$$2SiCl_4 + Hg(C_6H_5)_2 \longrightarrow 2C_6H_5SiCl_3 + HgCl_2$$

Arylsilanes are also accessible by the interaction of silicon tetrachloride, an aryl halide, and sodium [3]:

$$4C_6H_5Cl + SiCl_4 + 8\,Na \longrightarrow (C_6H_5)_4Si + 8NaCl$$

A valuable extension was made by Kipping, who introduced the use of Grignard reagents, with all their elegance and flexibility. All these synthetic methods permit the introduction of from one to four univalent organic radicals, either in one operation, by controlling the relative proportions of the reagents, or by successive treatment of the purified intermediate compounds with the same or different reagents:

$$SiCl_4 + CH_3MgBr \longrightarrow CH_3SiCl_3$$
$$CH_3SiCl_3 + C_2H_5MgBr \longrightarrow C_2H_5(CH_3)SiCl_2$$
$$C_2H_5(CH_3)SiCl_2 + C_3H_7MgBr \longrightarrow C_3H_7(C_2H_5)(CH_3)SiCl$$
$$C_3H_7(C_2H_5)(CH_3)SiCl_2 + C_6H_5MgBr \longrightarrow C_3H_7(C_2H_5)Si(CH_3)C_6H_5$$

An immediate consequence is that reaction cannot be confined to a particular intermediate stage, so that not only may yields be poor but the products may be difficult to separate by fractional distillation. Kipping's initial objective was to determine whether silicon resembles carbon in having an equispatial distribution of the four valencies. By the method outlined above he prepared a number

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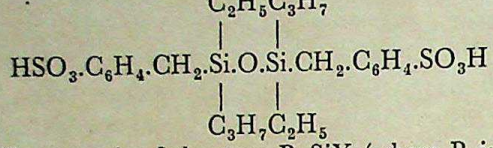
of asymmetric compounds and their salts with optically active bases, but was unable to resolve any compound containing a single silicon atom. He was, however, successful [4] in obtaining the optical antipodes of such compounds as 1, 2-dibenzyl-1, 2-diethyl-1, 2-dipropyldisiloxane-disulphonic acid[1]:



Compounds of the type R_3SiX (where R is a univalent hydrocarbon radical and X is a halogen atom or an alkoxyl group) readily hydrolyse to the corresponding silanols. These are usually high-boiling oils, or even crystalline solids, which may be readily dehydrated to disiloxanes. For example, triethylchlorosilane gives triethylsilanol (b.p. 184° C), which has an odour like camphor, and viscous hexaethyldisiloxane (b.p. 231° C):

$$(C_2H_5)_3SiCl + H_2O \longrightarrow (C_2H_5)_3SiOH$$
$$\longrightarrow (C_2H_5)_3Si.O.Si(C_2H_5)_3$$

Such structures do not admit a greater degree of complexity, but it is quite otherwise with the products obtained by hydrolysing compounds of type R_2SiX_2. By carrying out the hydrolysis under the mildest conditions it is possible to isolate the simple silandiols:

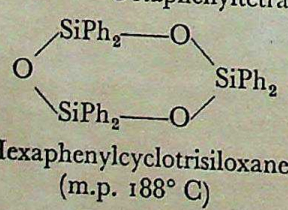
$$(C_2H_5)_2SiCl_2 + 2H_2O \longrightarrow (C_2H_5)_2Si(OH)_2$$

but these are very prone to undergo dehydration, and more complicated products usually arise, such as the syrup of high molecular weight obtained by Kipping and Martin [5] from diethyldichlorosilane. This syrup could be distilled without decomposition below 300° C, and possessed the empirical formula $C_4H_{10}SiO$. From diphenyldichlorosilane Kipping [6] was able to isolate the simple diphenylsilandiol, and both cyclic and linear condensation products of the following formulae:

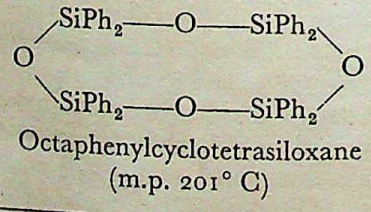
$HO.SiPh_2.O.SiPh_2.OH$
Tetraphenyldisiloxandiol (m.p. 113° C)

$HO.SiPh_2.O.SiPh_2.O.SiPh_2.OH$
Hexaphenyltrisiloxandiol (m.p. 112° C)

$HO.SiPh_2.O.SiPh_2.O.SiPh_2.O.SiPh_2.OH$
Octaphenyltetrasiloxandiol (m.p. 128·5° C)



Hexaphenylcyclotrisiloxane
(m.p. 188° C)

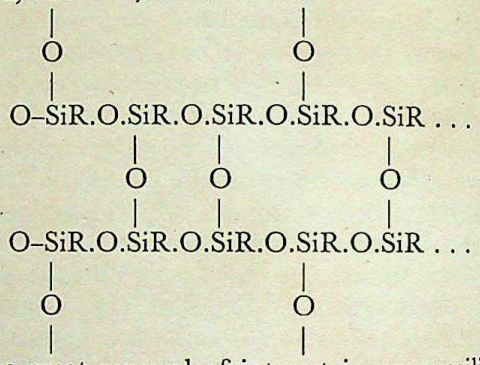


Octaphenylcyclotetrasiloxane
(m.p. 201° C)

Yet more complex compounds with longer chains and larger rings must account for the glue-like products into which the simpler compounds readily pass when heated. Intermediates of type $RSiX_3$ are hydrolysed to organosiloxanols:

$$R.SiX_3 + 2H_2O = R.SiO.OH + 3HX$$

These are usually amorphous powders or hard, brittle solids; many have no definite melting-point, and some are quite infusible. They consist of condensation products of varying degrees of complexity derived from the hypothetical organosilantriols ($RSi(OH)_3$), and may be of linear, cyclic, or cross-linked structure, the end-product of the dehydration process being cross-linked, insoluble, and infusible:



The great renewal of interest in organosilicon chemistry follows naturally from the intensive study and commercial development of high polymers. Here is a new class of highly condensed materials possessing a considerably greater degree of thermal stability than the accepted plastics. Their basic structure of recurrent siloxane units, analogous to that of the silicates, suggests that they may be good insulators of electricity. It would appear that this line of thought was being pursued by Russian investigators at an early stage, for in 1932 Dolgov [7] published a review of previous work on organosilicon compounds, and in 1935 Shtetter [9] patented the production of substituted chlorosilanes from silicon

[1] The system of nomenclature employed is that of R. O. Sauer [8].

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tetrachloride and the simpler unsaturated hydrocarbons such as acetylene and ethylene. A few years later, several papers were published by Andrianov [10] and by Kotow [11] on the condensation products of the alkyl and arylsiloxanols ($R_2SiO.OH$) and their application as heat-hardening resins. The products were too brittle for use alone, but when mixed with drying oils they gave satisfactory insulating varnishes.

In the United States, work on organosilicon compounds has been highly competitive. Initially there were three independent groups, represented by the Corning Glass Works, the Mellon Institute, and the General Electric Company, but at a later stage the first two and the Westinghouse Electric Corporation joined forces. Dr E. C. Sullivan, head of the Corning research department and discoverer of 'Pyrex' glass, desired a heat-resistant resin which could be used for impregnating glass fabric to give a flexible electrical insulation, and in 1931 Dr J. F. Hyde was assigned the task of making such a resin from organosilicon compounds. At the Mellon Institute, Dr G. R. McGregor went a long way towards an independent solution of the same problem before collaborating with Hyde. Other useful products were discovered, and it soon became necessary to begin manufacture. For this purpose the co-operation of the Dow Chemical Company was sought, and in 1943 the Dow-Corning Corporation was formed to manufacture and develop the new organosilicon products. These were dubbed 'silicones,' a term originally used by Kipping for the analogues of ketones. The Dow-Corning plant is based on the Grignard method of synthesis, and has a monthly output of 40–50 tons of various silicone products. The research and development programme of the General Electric Company has been most energetically carried out by a large group of competent research workers, notably by Dr E. Rochow, and this powerful concern will shortly be in a position to manufacture a complete range of silicone products. So far, production has been on a pilot-plant basis with a monthly output of about two tons. Of major importance has been the discovery of a new method [12] for producing organosilicon intermediates. This consists in bringing the vapour of an alkyl or aryl halide into contact with an intimate mixture of silicon and copper or silver at an elevated temperature:

$$Si + 2CH_3Cl \xrightarrow{Cu} (CH_3)_2SiCl_2.$$

The catalytic action of copper and silver is thought to be connected with the transitory formation of their organocompounds [13]:

$$CH_3Cl + Cu \longrightarrow CH_3CuCl.$$

The process is particularly effective with methyl chloride at 280–300° C, and leads to a complex mixture of methylchlorosilanes, chief of which is dimethyldichlorosilane (b.p. 70° C). Methyltrichlorosilane (b.p. 66° C) is also present in notable proportion, while trimethylchlorosilane (b.p. 57° C) and methyldichlorosilane (b.p. 42° C) are minor constituents. In the preparation of certain silicone products it is necessary to employ highly purified intermediates so that the degree of cross-linkage may be kept under close control. Owing to the proximity of their boiling-points, the methylchlorosilanes can be separated only in highly efficient fractionating columns (80–100 theoretical plates). This new synthesis is well adapted to large-scale production, and it may be expected that manufacturing costs will be lower than with the Grignard process. Unfortunately the direct synthesis is not uniformly successful, so that wherever it proves impracticable or uneconomic the Grignard method will still hold sway.

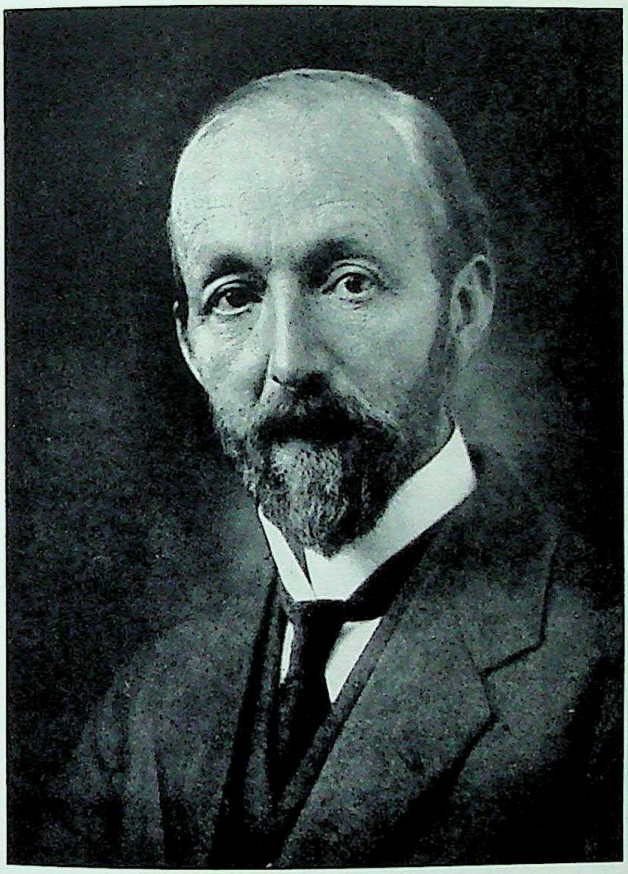

FIGURE 1 – *Professor F. S. Kipping, F.R.S.*

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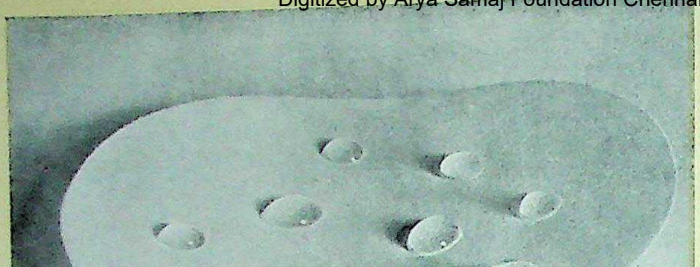

FIGURE 2 (*above*)—*Water-repellent filter paper. The filter paper was exposed for fifteen seconds to the vapour of methyltrichlorosilane and then to gaseous ammonia. The water drops are not absorbed and do not wet the paper, which retains its strength and permeability to gases and most other liquids.*

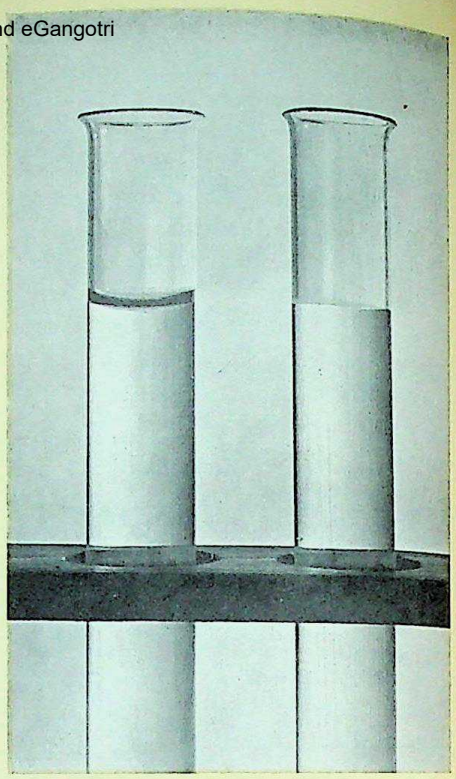

FIGURE 3 (*right*)—*Glass tubes containing water. On the left is a normal clean test tube, showing the meniscus, characteristic of a liquid which wets glass. The right-hand tube is a similar tube, the inside of which has been in brief contact with liquid dimethyldichlorosilane and then thoroughly cleansed with alcohol and ether. The water surface is flat because the glass is not wetted.*

FIGURE 4*a* – *Water flowing down a clean glass plate inclined at 35°. The thin and wide spread shows that the glass is thoroughly wetted. The shape of the moving water film remains substantially unaltered.*

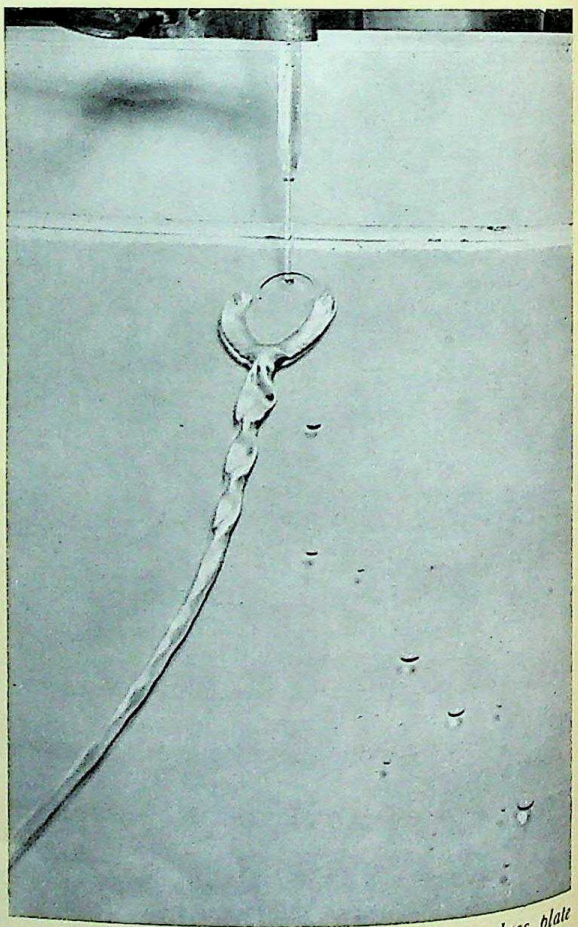

FIGURE 4*b* – *Water flowing down a similar glass plate which has been previously rendered water-repellent by contact with liquid dimethyldichlorosilane. The water runs down the glass with a minimum area of contact, and by continually changing its path produces an effect reminiscent of the violent movement of a serpent.*

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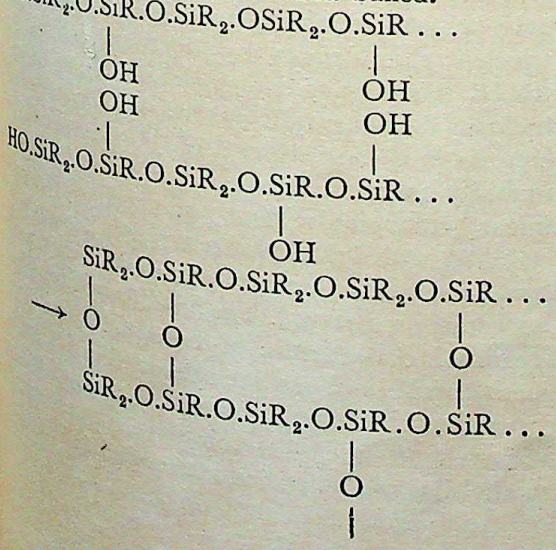
An interesting property of certain organosilicon compounds is their ability to produce water-repellent surfaces on glass and ceramics, and to waterproof materials such as paper and cotton [14] which consist chiefly of cellulose (see figures 2, 3, 4). This result may be achieved by a short exposure to the vapour of dimethyldichlorosilane. It is believed that this material reacts with superficial hydroxyl groups and metallic atoms to give a chemically bound, water-impermeable layer of dimethylsiloxane groups. In the case of cellulosic materials it is necessary to neutralise immediately afterwards in order to prevent the harmful action of hydrogen chloride. An alternative and less objectionable method is to impregnate with a liquid polydimethylsilicone and then to subject to a suitable heat-treatment. This is particularly suitable for ceramics, and was employed to safeguard radio and radar equipment against failures due to the deposition of water films on such ceramic parts as coil formers, the bases of high-frequency transformers, and wire-wound resistors. Paper filters waterproofed in this way were fitted to certain respirators to prevent damage by immersion. It is to be noted that these water-repellent surfaces are eventually obliterated by films of grease and dust. Great care must therefore be taken in their preparation and subsequent treatment; they must not be handled, and should be used only under conditions which substantially preclude contamination.

Silicone resins [15] are produced essentially by condensing a chain-forming intermediate with one capable of cross-linkage; they consist of long-chain molecules which possess a controlled amount of hydroxyl groups. Dissolved in toluene they form viscous varnishes which pass into insoluble coatings when dried and baked.



The baking temperatures are comparatively high (175–250° C), and thereafter the resins may be maintained at 175–200° C for long periods without depreciation. For any given pair of intermediates the amount of cross-linkage must be kept within narrow limits, outside of which the products are of no value as coating materials. This range can be found only by trial, and it will be apparent from the variety of organic radicals that may be present that a great deal of experimentation is necessary to find resins with the desired combination of properties. Those now available have been selected for specific applications. There are insulating varnishes for coating wires, and resins for impregnating glass cloth. Layers of resin-impregnated glass fabric may be bonded together, by heating under pressure, into strong panels or tubes. Other resins may be mixed with thermally stable pigments to give heat-resistant paints and enamels.

The principal object in developing silicone resins was to provide improved forms of insulation for electrical machines such as motors, generators, and transformers [16]. Conventional insulations involve the use of organic varnishes and drying oils, paper, and cotton, and are relatively short-lived when used in heavy-duty machines, particularly those which operate at high ambient temperatures and with occasional periods of overload. Class A insulation, comprising organic varnishes, paper, and cotton, is limited to 100° C, as determined by the resistance method. If the paper and cotton are replaced by glass or asbestos cloth (Class B), the limit is raised to 120° C. From a series of accelerated tests [17] at temperatures up to 300° C it is concluded that insulations based on silicone resins, glass, and asbestos cloth, mica, etc., will permit a limit of 160° C with normal expectations of life. This means a greater degree of freedom for the designer. Silicone insulation is not only heat-resistant but resistant to water and aqueous solutions, and so should find application in mines, and in factories where corrosive chemicals are handled.

The need for a heat-resistant substitute for the rubber insulation on electrical leads has been met by the truly remarkable silicone rubber [18]. This differs from all other rubber-like materials in that its molecular backbone contains no carbon atoms, since it consists of a long chain of dimethylsiloxane groups:

$$HO.Si(CH_3)_2.O.Si(CH_3)_2 \ldots O.Si(CH_3)_2.O.Si(CH_3)_2.OH$$

It is produced from the hydrolysis product of

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substantially pure dimethyldichlorosilane by heating with hydrochloric acid and the active metallic chlorides, and resembles a translucent gum or sticky jelly. To develop rubber-like properties, cross-linkages must be established between the long-chain molecules by some process of vulcanization, but, as it is saturated, the conventional vulcanization with sulphur is not possible. The method used appears to be one of controlled oxidation, and is probably induced by heating with an organic peroxide. The gum is compounded with suitable proportions of inorganic fillers and vulcanizing agent, and is then moulded, pressed, or extruded at about 150° C. This develops dimensional stability, but the full strength is not attained until after a lengthy cure at 250° C. The tensile strength is lower than that of most other rubbers, being only about 650 pounds per square inch, and the maximum elongation varies between 100 and 300 per cent. The tear-resistance is also poor, but can be improved by incorporating a fabric. Silicone rubber has outstanding heat and oxygen resistance, and has been used extensively as gasket material for joints exposed to temperatures up to 200° C or more.

The erection of the Dow-Corning plant in 1943 was due to a large demand for a material capable of sealing the ignition harnesses of aircraft engines against corona discharge. This trouble is encountered at high altitudes, and may quickly lead to engine failure owing to destruction of insulation. It was found that a grease made by hydrolysing a mixture of silicon tetrachloride, dimethyldichlorosilanes, and methyltrichlorosilanes was eminently suitable for this purpose. It is a colourless, translucent grease which does not change in consistency over the temperature range −40° C to above 200° C, and although its electrical resistance is high it does not form an insulating layer at the disconnectable junctions employed on ignition harnesses. The grease is not only without harmful action on rubber and synthetic insulations but has proved to be a good lubricant and preservative for these materials. When electrical discharge takes place in the grease some carbon is formed, but the principal decomposition product is silica, and so tracking is not as serious as with ordinary organic insulators. The grease was applied to disconnectable junctions and to spark-plug wells in such a way as to exclude air from them. At the same time ingress of moisture was prevented, and so short-circuits due to water films were prevented. During the war silicone ignition-sealing grease contributed in no small way towards the safe operation of Allied aircraft at high altitudes.

The grease found further application in radio and radar equipment, and was used as a lubricant for the shafts and other movable parts of rotating antennae and for the swivel joint in the oxygen supply line to rotating gun turrets on aircraft. It has also been used as a lubricant for the rubber bags used in the low-pressure moulding technique with contact resins. A high-vacuum grease is particularly useful on account of its low vapour pressure, high film strength, and ability to wet all types of surfaces. Special greases thickened with carbon black and with metallic soaps are suitable for lubricating high-speed bearings that must operate at temperatures as low as −75° C or as high as 150° C.

On hydrolysis, dimethyldichlorosilane gives a variety of condensation products of dimethylsilandiol, some being cyclic like hexamethylcyclotrisiloxane (m.p. 65·5° C, b.p. 135° C), while others are linear. Wide variation of molecular complexity is possible, and hence the liquid products cover a wide range of boiling-point and viscosity [19]. These silicone fluids possess many interesting and useful properties; for example, owing to their low molecular cohesion [20] the change of viscosity with temperature is remarkably small. They have high electrical resistance and low power factor up to 10^7 cycles per second. Various artifices are employed to modify and extend the range of available liquids; the viscosity may be increased by heating in air, by boiling with hydrochloric acid, and by condensation with boric anhydride. Other methods are to condense with a lightly chlorinated polymer or with trimethylsilanol (see top of page 35).

In this last process [21] it is claimed that any given condensation product of dimethylsilandiol may be substantially converted into products of selected chain-length by treatment with controlled amounts of trimethylsilandiol, or its anhydride hexamethyldisiloxane, in presence of concentrated sulphuric acid. Owing to their inability to condense further, these end-stopped linear compounds have outstanding thermal stability. Polydimethylsiloxanes may be prepared by an interesting method which avoids the use of pure starting material. The brittle gels obtained by hydrolysing a mixture of dimethyldichloro- and methyltrichlorosilanes are submitted to dry distillation, preferably in the presence of a strong base like sodium hydroxide, when substantially pure polydimethylsiloxanes volatilize, leaving the infusible condensation products of methylsiloxanol behind [22].

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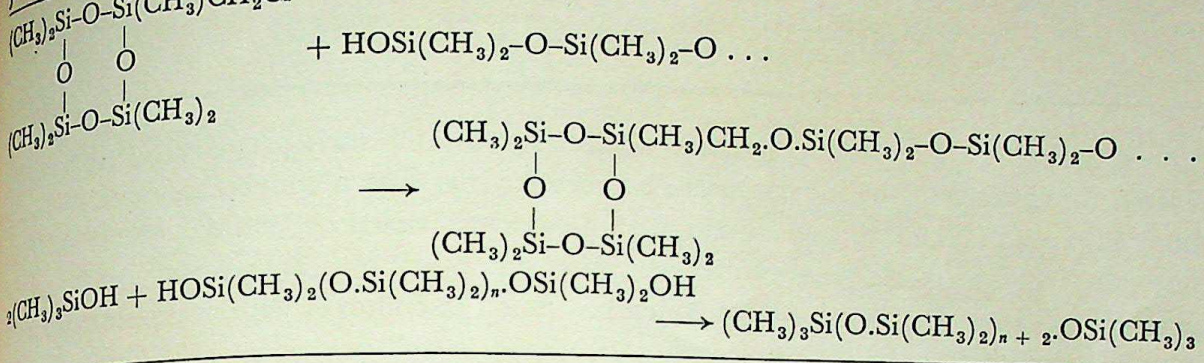

Their combination of low viscosity-temperature gradient, wide fluid range, and high compressibility makes certain of these liquid products eminently suitable for use in sensitive hydraulic systems, damping devices, and shock absorbers. Others are effective as mould-release agents, fibre lubricants, and water repellents, and certain exceptionally stable high-boiling products are suitable for use in diffusion pumps, high-temperature baths, and thermally responsive devices. Silicone fluids are remarkably effective in reducing the foaming tendency of hydrocarbon oils, even at dilutions as low as 1 in 10^6.

When delivering the Bakerian lecture to the Royal Society in 1937 Kipping reviewed the organic chemistry of silicon, and concluded with the following words:

'Most, if not all, of the known types of organic derivatives of silicon have now been considered, and it may be seen how few they are in comparison with those which are entirely organic; as, moreover, the few which are known are very limited in their reactions, the prospect of any immediate and important advance in this section of chemistry does not seem to be very hopeful.'

That events have proved otherwise is no reflection on his judgment. Doubtless the experimental difficulties with which the subject bristles weighed heavily in the balance, but fortunately human endeavour is cumulative: each new worker starts with vigour and enthusiasm from the advanced bases provided by his predecessors. With characteristic faith, vision, and capacity for intensive work, American investigators and industrialists have been quick to translate the academic results of an English chemist into a fascinating new field of chemical technology. The debut of silicones has been brilliant and full of promise, but their present high cost[1] places them in the luxury class of chemicals. So far, their employment has been restricted to applications in which a valuable advantage can be secured only by making use of their unique properties. Future development must depend on their ability to compete with other new materials on a cost basis, and it may be anticipated that much attention will be given in the near future to the possibility of devising new and cheaper methods for producing the fundamental intermediates.

[1] On the basis of their silicone content, the cost is about seven dollars per pound.

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The senses of bats

BRIAN VESEY-FITZGERALD

The remarkable ability of bats to avoid obstacles and catch their prey in the dark has been known for centuries, but it is only during recent years that a convincing explanation has been advanced. There is now a great deal of evidence, based on both laboratory and field research, that bats guide themselves by emitting supersonic sounds and receiving the echoes from objects in their path, a system which has much in common with navigation by radar.

Of all the many problems which bats set for the inquiring naturalist, none has been more puzzling than that presented by their flight at night: the way in which they catch the insects upon which most of them feed (in the case of British bats, upon which *all* of them feed) without colliding with objects in their path. The flight of bats is rapid and the course erratic, frequently through thick woods or the narrow winding passages of caves, often in total darkness. It has always seemed unlikely that animals with such small eyes could see well enough in the dark to fly in such surroundings without mishap. Many experiments have been tried with captive bats to demonstrate their ability to avoid obstacles which they could not see. Towards the end of the eighteenth century the Italian scientist, Lazzaro Spallanzani, found that bats which he had blinded could fly about a room, avoiding the walls, the furniture, and silken threads stretched across their path. A Swiss scientist, Louis Jurine, confirmed this and made the additional discovery that bats lost their ability to avoid obstacles when their hearing was interfered with. Cuvier poured scorn on these findings, and they were forgotten for a century and a half. All that was remembered was that a blinded bat could fly perfectly surely. But the uncanny ability remained, and all sorts of theories were advanced to account for it. It was suggested, for example, that bats were very sensitive to changes in atmospheric pressure.

Then, in 1920, Professor Hartridge suggested that bats when flying in the dark were probably able to ascertain the position of obstacles by means of supersonic sounds emitted by the animals and reflected to their ears. Twenty years later, after the development of radar as an operational system, Griffin and Galambos working in America were able to prove him correct.

Both radar and sonar are, of course, founded on the same fact, namely that if a short burst of energy is sent out and the time taken for the echo to come back is noted, then, if the speed at which the energy travels is known, the distance of the object can be accurately calculated. Moreover, by sending the energy down a narrow beam the bearing of the object can be accurately determined. In radar the energy used is in the form of electromagnetic waves; in sonar (the method by which the depth of water is measured) ordinary sound waves are used. In their direction-finding bats use not audible sound waves, but, as Hartridge suggested and as Griffin and Galambos have proved, supersonic waves. The range of frequencies that a normal human being can hear is from about 16 vibrations a second to about 30,000 a second. Middle C is 256 vibrations a second. The range of frequency of the supersonic waves used by bats is from about 25,000 to 70,000 a second, and is thus mostly above the limit of human hearing.

Griffin and Galambos began their work by confirming that blindfolded bats are able to fly surely. They then confirmed Jurine's discovery that if the hearing of a bat is impaired it is unable to avoid obstacles when flying. Indeed, they found that a bat with both ears covered is most reluctant to take wing at all, but that a bat with one ear covered will fly with moderate success, though it will be unable to avoid all obstacles. These simple experiments indicated that bats are made aware of the position of obstacles which they cannot see by means of sound waves reflected from them. They then covered the noses and mouths of their bats, but left the ears uncovered, and found that again the animals were unable to fly with certainty. They thus proved that the sound waves reflected by objects must be produced by the vocal apparatus of the bats themselves.

Their further experiments were conducted with the aid of an electronic apparatus known as a supersonic analyser. This consists essentially of

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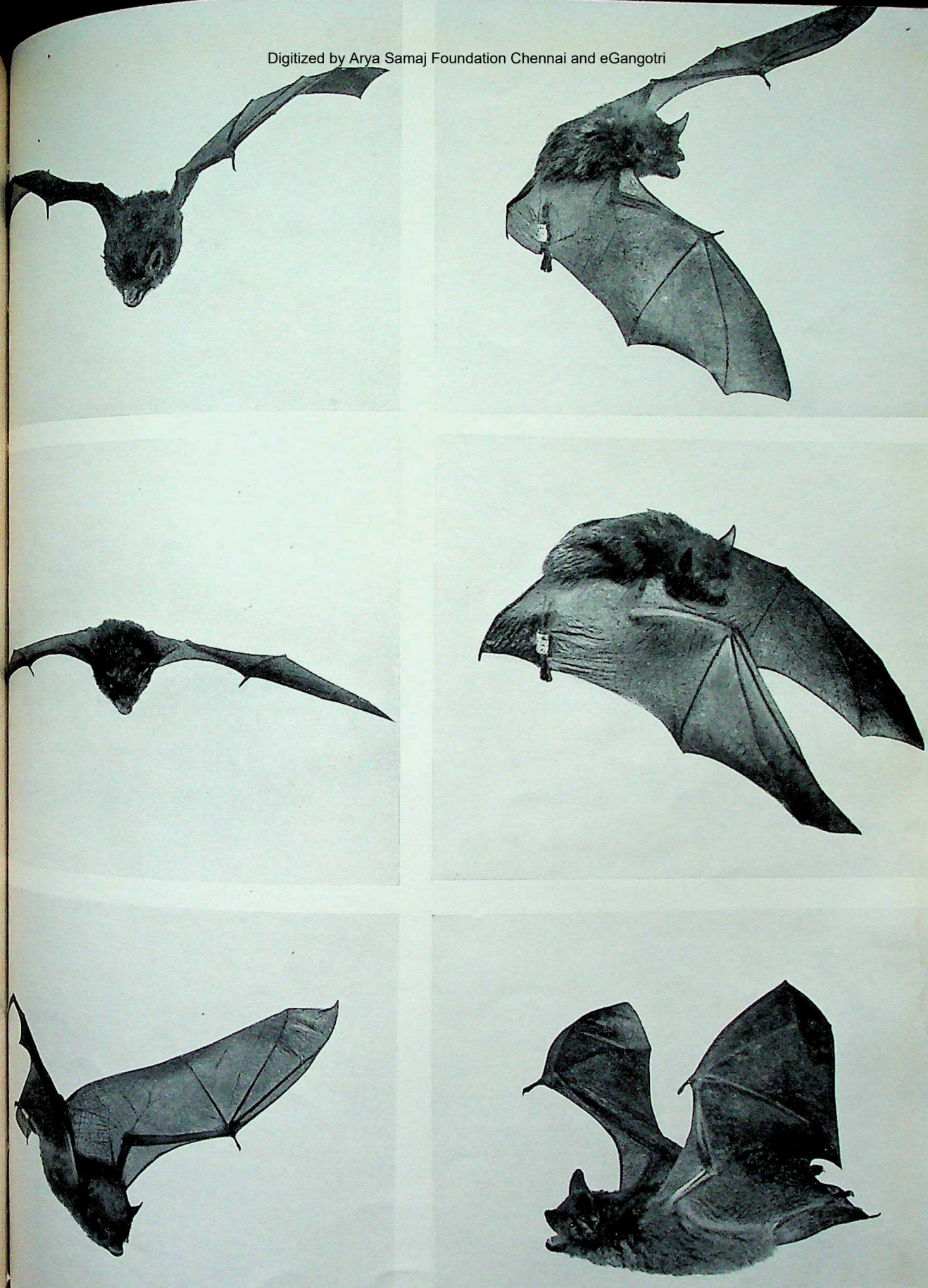

FIGURES 1–3 (*read down*)–*The wing action of a bat in level flight, towards the camera. Bats make between fifteen and twenty such of the wing a second, and fly at about ten miles an hour.*

FIGURES 4–6 (*read down*)–*Level flight broadside to the camera. Bats fly by raising the wings partly folded and bringing them sharply down and forward. Note that in all these photographs the mouth is held open.*

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FIGURE 8 – *Swooping to alight. Note the depressed interfemoral membrane. All these photographs were taken at 1/2000 sec.*

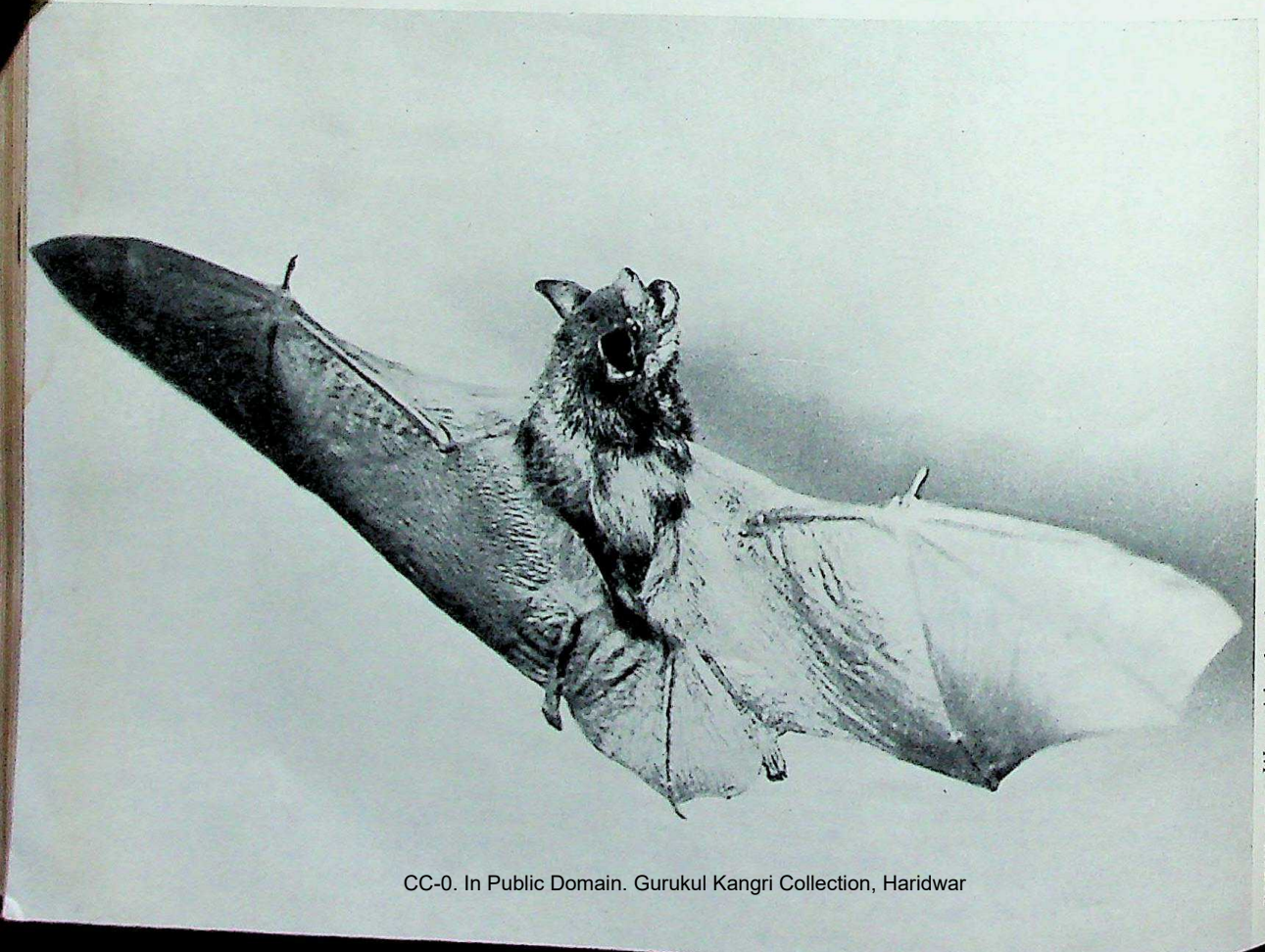

FIGURE 7 – *Warned by the echo, a bat banks sharply to avoid a wall. How close it has come without accident is shown by the shadow.*

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a microphone sensitive to supersonic vibrations, a magnifier which amplifies them and converts them to vibrations of a lower frequency, and a recorder which traces a graph on paper when supersonic sounds are received. The analyser measures the frequency of any supersonic vibrations it may pick up. By means of this instrument it was discovered that bats make supersonic sounds at frequent intervals almost all the time. The frequency of the vibrations varies, of course, but it is most usually about 50,000 a second, and at this pitch each squeak lasts for a little less than one two-hundredth of a second.

Now, it is evident that the more frequently squeaks are emitted the fuller the information received. It has been proved that a bat at rest emits a supersonic squeak about ten times a second, but that as soon as it takes wing the rate goes up to about thirty a second. That was to be expected, since a bat on the wing obviously needs more information than a bat at rest. Griffin and Galambos further found that the closer a bat approached an obstacle the faster became the rate of squeaks, rising to fifty and sometimes even to sixty a second, and dropping to normal as soon as the obstacle was passed. The rate of squeak is, of course, governed by the distance from the object, for there must be time for the echo to come back before the next squeak is sent out.

The supersonic tone is not the only sound produced by bats. In addition to the supersonic squeak, which cannot be heard by human beings, they produce three other kinds of sound: (1) the ordinary voice, which is the flight call, and which Hartridge has named the signalling tone; (2) a buzz, which is audible if one is quite close to the animal; and (3) a click, which is usually audible at a distance of several feet. I am not competent to say whether the buzz differs in any way with the species; it sounds exactly the same to me whether emitted by a Serotine (*Eptesicus serotinus*) or a Pipistrelle (*Pipistrellus pipistrellus*), nor can I distinguish any difference between the clicks emitted by the different species. The flight calls, however, are quite distinct. It is possible to distinguish between the species on the wing by means of their flight calls (it is also possible with practice to distinguish between the types of flight), and I have elsewhere attempted to translate the differences between the calls of the various species to paper. It has been shown that the buzz and the click are accompanied by the supersonic tone. In the case of the click there is a single short burst of supersonic energy, but in the case of the buzz there is a continuous evolution of the interrupted supersonic tone. The flight call, however, may be produced by itself or it may be accompanied by the supersonic tone. Some bats, notably the Lesser Horseshoe (*Rhinolophus hipposideros*), have a considerable vocabulary of ordinary sounds, whereas others, notably the Whiskered (*Myotis mystacinus*), scarcely ever make a sound of this sort. I have never heard the Whiskered utter a sound on the wing, and of the many I have kept in captivity only a few have uttered faint grunts, and those very occasionally, when at rest.

How these four different types of sound are produced is not yet clear, but examination of the vocal organs of bats shows that they are very different from those of other animals. The larynx, which in most animals is built of cartilage, in bats is made of bone and is comparatively a massive structure with large and powerful muscles. The strength of the bat's larynx and its small size are obviously well adapted to the production of supersonic sounds, for there must be tremendous energy in the supersonic squeaks as compared with the audible squeaks. The higher the note and the greater the frequency, the greater the energy.

Though it is not yet known exactly how the supersonic vibrations are produced, it is known how the bat avoids hearing the squeak. It is, of course, essential that only the echo should be heard by the bat. The same difficulty had to be overcome in radar transmission. In order to ensure that only the echo is picked up by the receiver, this is suppressed while the transmitter sends. Something of the same kind happens in the bat when emitting the supersonic tone. Griffin and Galambos found that while the squeak is being made a muscle in the ear contracts momentarily, shutting off the squeak, and permitting only the echo to be heard.

Bats are not the only creatures with the power of echo-location. The tapping of Blind Pew's stick is an example of the same process, and many blind human beings develop what appears to be an uncanny ability to move about without striking obstacles. Nor are bats the only creatures able to hear supersonic vibrations: dogs, for example, are often trained on the Galton whistle. But so far as is known at present bats are the only creatures that emit supersonic vibrations and guide themselves by the reflections. This important discovery, however, still leaves unanswered many questions about the behaviour of bats, and, as is the way with important discoveries, poses a number of fresh problems.

FIGURE 8 – *Swooping to alight. Note the depressed interfemoral membrane. All these photographs were taken at 100,000 sec.*

FIGURE 7 – *Warned by the echo, a bat banks sharply to avoid a wall. How close it has come without accident is shown by the shadow.*

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Invariably the first question that is asked is: Why do not the bats become confused between the echoes from their own squeaks and the echoes from the squeaks of their neighbours? It might be thought that with a large number of bats of the same species together in a cave or in the roof of a church, and all uttering supersonic squeaks, confusion would be inevitable. But it must be remembered that supersonic squeaks do not travel far, for their energy is quickly dissipated in the air. It has been shown that the supersonic squeaks of bats travel only about fifteen feet, and that they are able to give a useful echo only up to about twelve feet. In other words, provided that the bats are not crammed close together, there is very little likelihood of confusion. But, as everyone with any field experience of bats knows, they very often are crammed close together, yet there is no confusion. It seems evident that there is a difference in the frequency of the vibrations made by each bat. A very slight difference in frequency would be sufficient to enable each bat to recognize its own voice.

There remain a number of problems to which no answer has yet been given. Firstly, do bats emit the supersonic squeak through the mouth or the nose, or both? All the British bats are insect-eaters, and all, with the possible exception of the Barbastelle (*Barbastella barbastellus*), habitually fly with their mouths open. Furthermore, all the British bats capture their prey while in flight, and most of them take flying insects. What happens when the bat closes its mouth on catching an insect? Does echo-location cease (in which case the bat must fly blind) or does it continue through the nose? We do not know. In the Greater Horseshoe (*Rhinolophus ferrum-equinum insulans*) the epiglottis does not open into the back of the mouth as in most animals, but is projected up into the roof of the mouth, fitting into the rear opening of the nasal passages. It is not fixed in this position, and can probably be withdrawn, but the arrangement suggests that the supersonic squeaks, in the *Rhinolophidae* at any rate, are emitted through the nose, and this suggestion receives additional support from the extraordinary skin development on the muzzles of these bats. While the purpose of this appendage, which in some species attains an astonishing complexity, is not known, it has been suggested that it is concerned with directing the squeak into a narrow beam so that the bat's knowledge of its position is greatly increased. Be that as it may, I have no doubt from long personal observation that the Horseshoes have a much finer appreciation of position than other British bats, and especially is this so in the case of the Greater Horseshoe. Indeed, this species is quite uncanny in its judgment of distance. Bats normally hang head downwards, suspended by the toes. It is the usual practice for bats to land head upwards and then to shuffle round until they can get a grip with the toes, but the Greater Horseshoe is accustomed to turning a somersault in the air and gripping straightway with the toes, landing, in other words, in the head-downward position. Very rarely indeed have I seen a bat miss its hold, and there appears to be no slackening of speed as the resting-place is approached. Some of my captive Greater Horseshoes used to sleep under a sideboard, and when they were hanging there was little more than a couple of inches clearance from the floor, yet they would fly under the sideboard, turn their somersaults with absolute certainty, and hang by the toes. And many, many times have I watched this acrobatic performance when they have been hanging from picture-rails and so forth.

There is a marked difference in the structure of the ear in the *Rhinolophidae* and in the *Vespertilionidae*. In the former the pinna is comparatively simple in build, but in the bats without nose-leaves the ear is a much more complex structure, characterized by a great development of a lobe known as the tragus. This is especially well seen in the Long-eared (*Plecotus auritus*), in which species it stands up like a second pinna. It has been suggested that the tragus is in some way connected with echo-location, and the fact that the bats with nose-leaves have no tragus while the bats with the tragus have no nose-leaves is surely significant. It would appear that the two developments must in some way perform similar functions.

It is, I think, noteworthy that the Long-eared, in which there is such a marked development of the tragus, is in comparison with other bats of the same group a master of flight in confined quarters. Most bats, when flying to their feeding-grounds, do so at a considerable height; the Long-eared does so very close to the ground, often at a height of no more than a few inches, and the flight is fast, direct, and confident. Furthermore, the Long-eared captures comparatively few insects in flight, preferring to pick them off the leaves of bushes and trees, a habit which entails the nicest judgment of distance.

Two other British bats, Natterer's (*Myotis nattereri*) and the Whiskered (*M. mystacinus*), have the habit of picking their prey from foliage rather

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than taking it in flight. Natterer's is fairly impartial, but the Whiskered very rarely captures a flying insect, preferring to search the hedgerows and fences, especially for spiders, of which it is inordinately fond. Both species have a well-developed tragus, and in both, but more particularly in Natterer's, there is a marked development of the glandular pads on the face.

How bats find their prey is a mystery that has not yet been solved. It is certain that they cannot find it by sight, and there does not seem to be any evidence that their powers of scent are particularly acute. How, then, does the Noctule (*Nyctalus noctula*), flying high and fast, find its prey? If you throw a pebble into the air beneath a hawking Noctule, the bat will dive on to it, swerving away from it at the very last moment without touching it. Attach a fly to a long line and make casts into the air while bats are hawking and you will have them diving at the fly, but it is very unlikely that you will catch one. Daubenton's bat (*Myotis daubentonii*) is sometimes caught on the flies of anglers, but almost always by the wing. I do not think that there has been a single instance of the bat being caught by the mouth, which suggests that at the last moment (but too late to avoid contact altogether) it has realized its mistake. All this suggests that the supersonic squeak sends back an echo from anything flying into or across the path, but it does not explain how the bat knows that that something is worth investigating. Yet I have never seen one bat dive at another, even when there have been many flying at random in a confined area. Nor does it explain how the Long-eared and the Whiskered know that there is an insect or a spider on what their echo-location must have told them is an obstacle to avoid. Yet in a long experience of Whiskered bats, I have not seen one hit a fence or make fruitless visits along a hedge.

One would be inclined to say that the supersonic tone was even more selective than we know it to be were it not for certain things that field experience has brought to notice. I have seen bats of different species collide in mid-air—on one occasion a Noctule with a Serotine (and both animals were killed), and on another occasion a Pipistrelle with a Barbastelle (when the Pipistrelle was killed). These accidents happened during the evening hawking, and one can only suppose that at the time echo-location had stopped, possibly because both animals had captured insects and their mouths were closed.

Field experience shows too that there are times when echo-location does not function at all. I have caught many bats by netting their dens of a summer night. At one time, anxious to discover whether bats flew at night or not—it was at that time thought that they had an evening and a morning flight only—I made a number of all-night watches at dens of Noctule, Whiskered, Pipistrelle, Serotine, and Natterer's, and, after the bats had left the hole for the evening flight, netted the entrance. I caught many bats (and at almost all hours of the night) in the nets, trying to get back to the holes. At that time nothing was known about supersonic vibrations in connection with bats, and I did not think that there was anything odd about it. But in the summer of 1946, realizing that the supersonic tone should have warned them of an obstruction, I repeated the process at dens of Noctule, Whiskered, Daubenton's, and Serotine, with the same result. The bats appeared to be quite unaware that there was an obstruction and flew straight into the nets. Later I covered the entrance hole to a Noctule den with thick brown paper, and even this did not seem to be indicated to the bats, which flew straight into it. Before returning to their den Noctules fly round the tree and in and out among the branches with never a false movement, yet they are unaware of an obstruction at the very entrance to their sleeping-quarters. It seems evident that echo-location, for some reason, is shut off at that moment.

On the other hand, it seems to operate to some extent during hibernation. Everyone who has entered a hibernaculum of bats must have noticed the tremor that goes through the sleeping creatures at the first presence of a stranger. They are asleep, and incapable of movement, but there can be no doubt at all that they are aware.

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The meaning of resonance in quantum chemistry

C. A. COULSON

The system of equations known as quantum mechanics is unquestionably one of the most important discoveries in the history of science. A particularly interesting chemical application of it is the theory of resonance. This theory, of which a general account is given here, provides a formal and logical explanation of the properties and reactions of a very diverse range of substances. Of outstanding interest is the close similarity between the resonance structures for benzene and those advanced by Kekulé as long ago as 1865.

Resonance in quantum chemistry is a comparatively recent idea, which owes both its birth in 1933 and its early development almost entirely to the work of Linus Pauling in the United States. It is concerned with the way electrons behave in molecules. But before we can understand this we must go back to the individual atoms out of which molecules are formed and ask how the electrons move there; after that, we can discuss their behaviour in simple molecules, and this will lead us almost immediately to the concept of resonance.

The important point about the motion of an electron in an atom is that, since the electron is so very tiny and moves so very fast, we can never measure exactly where it is, and can at best get a kind of blurred pattern. This is quite understandable when we realize that the average velocity of an electron in an atom is at least two million miles per hour, and its orbit is less than one hundred-millionth of an inch across. The shape of this pattern may be calculated mathematically from the so-called Schrödinger Wave Equation. These calculations are quite elaborate, and for our present purposes it is sufficient to say that, although we can never tell exactly where an electron is, we can state that there is a very high probability (e.g. 95 per cent.) that it is within a certain definite volume. Different electrons in an atom will have volumes of different shapes, which they may be said to 'occupy.' In figures 1 and 2 we show these boundary contours for the electrons in hydrogen and oxygen atoms. In hydrogen the one electron lies within a spherical volume of diameter roughly 10^{-8} cm. In oxygen, with eight electrons, two of them (the inner 1*s* or K-shell electrons) have volumes of the same kind but only one-eighth as large; two more (the 2*s* electrons) have spherical volumes of about the same size as in hydrogen; the remaining four (2*p* electrons) lie within boundaries somewhat similar to a dumb-bell or a cottage-loaf in shape. The normal oxygen atom could be pictured as a superposition of all these patterns.

The 'shape' of a molecular electron in a diatomic molecule is not essentially different from

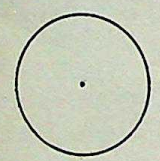

FIGURE 1 (*left*) – *Boundary contour for hydrogen atom.*

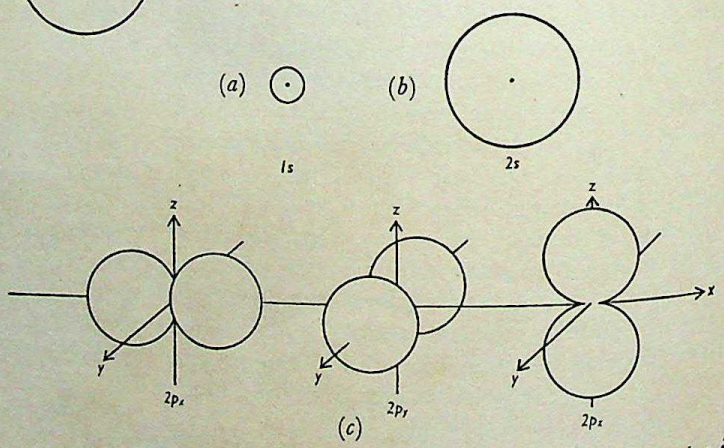

FIGURE 2 – *Boundary contours for oxygen atom. An oxygen atom has its nucleus at the origin and:*

(*a*) *Two electrons in a 1s volume.*

(*b*) *Two electrons in a 2s volume.*

(*c*) *Two electrons in one of* $2p_x$, $2p_y$ *or* $2p_z$ *and one electron in each of the others.*

For further description see above.

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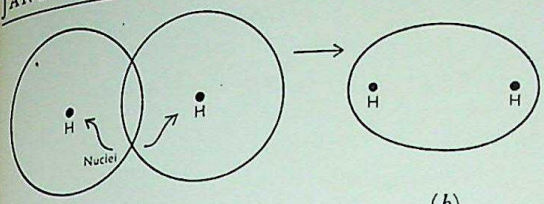
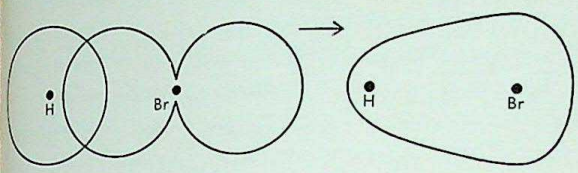


(*a*) (*b*)

FIGURE 3 – *The* H–H *bond.*

(a) Electron volumes for a pair of isolated hydrogen atoms. (b) Electron volumes for a hydrogen molecule. Two electrons in an orbit (b) comprise the H–H *bond.*



(*a*) (*b*)

FIGURE 4 – *The* H–Br *bond.*

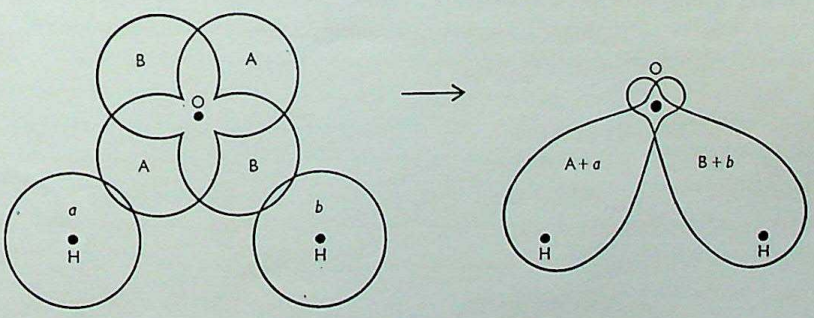
(a) Electron volumes for isolated hydrogen and bromine atoms.

(b) Electron volumes for H–Br *bond electrons. Two electrons in an orbit (b) comprise the* H–Br *bond.*

that of an atomic electron. The first important characteristic, originally noted by G. N. Lewis in 1916, is that it requires two electrons to establish a single bond between two atoms, as in H_2 or HCl, and four electrons for a double bond, as in O_2. The exceptions to this rule, which are called the 'odd molecules,' such as NO, are odd in more senses than one, and need not be considered in a preliminary account of the theory of chemical binding. The second characteristic is that electrons not involved in the formation of a bond have distinguishing patterns almost identical with those in isolated atoms. When describing the orbits of electrons in molecules, therefore, we need concern ourselves only with those electrons which actually form the bond. These orbits will be similar in general terms to the atomic patterns, except of course that they include two nuclei and may be called bicentric. They are to be interpreted as meaning that although we cannot precisely define the position of these valency electrons, each one is, for practical purposes, effectively confined within a certain contour whose shape may be determined mathematically. Figure 3 (b) shows the contour for molecular hydrogen (H_2), from which we see that the H–H bond is due to two electrons whose orbits distribute them fairly uniformly within a symmetrical sausage-shaped volume. This figure also shows how closely the molecular pattern may be regarded as compounded out of the separate isolated atomic patterns shown on the left. Figure 4 shows how the bond in HBr derives from a molecular pattern composed of a hydrogen 1*s* pattern (as in figure 1) and a bromine 4*p* pattern somewhat similar to that shown in figure 2 for oxygen. Once again the molecular pattern is symmetrical around the axis of the bond, though now, on account of the greater electron-attracting power of the bromine atom, it leans over more to the bromine end of the bond. Two electrons in a bond pattern such as figure 3 or 4 are said to be paired together; in quantum-mechanical language they have their spins opposed to one another. Together they may be said to form an electron-pair bond.

With polyatomic molecules a similar situation occurs. Each bond is formed by two electrons, which are paired together. These each have a pattern which embraces two atomic centres and is closely equivalent to a combination of atomic patterns from the two atoms concerned. The atomic orbits which are thus synthesized into a molecular orbit are always those which overlap one another as much as possible. This, though there is no space to elaborate it here, is really the basis of the theory of valency, and enables us to predict the characteristic valency angles of stereochemistry. Figure 5 shows how the two O–H bonds in water (H_2O) are approximately at right angles, and how they are formed by synthesis of a hydrogen 1*s* pattern and an oxygen 2*p* pattern.

This brings us to resonance itself. As a rule,



(*a*) (*b*)

FIGURE 5 – *The water molecule.*

(*a*) *The separate atomic electron patterns.*

(*b*) *The molecular electron patterns.*

Two electrons in each pattern $A + a$ *and* $B + b$ *give rise to the two* O–H *bonds.*

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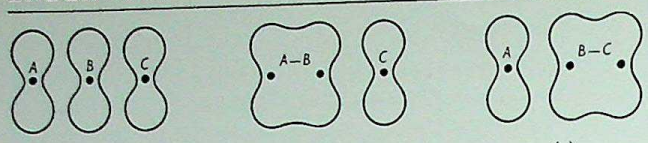


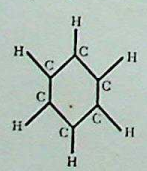
(*a*) (*b*) (*c*)

FIGURE 6

(*a*) *Three isolated unpaired atomic patterns.*
(*b*), (*c*) *Alternative pairings to form molecular patterns.*

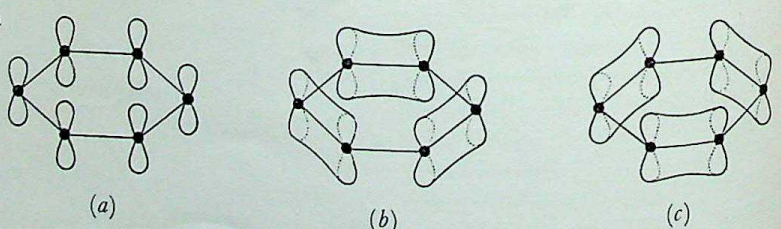
there is no difficulty in saying how the atomic patterns are combined to form molecular patterns localized between two nuclei and giving rise, if there are two electrons concerned, to a normal single bond, and if there are four electrons, to a normal double bond. The criterion that the component atomic patterns are to overlap as much as possible is a sufficient guide. For example, in figure 5 it would be illogical to combine the oxygen pattern *A* with the hydrogen pattern *b*, since the two patterns scarcely overlap at all, whereas oxygen *A* and hydrogen *a* do overlap fairly considerably. But there are occasions when this combining together of atomic orbits is not so unequivocal. For suppose (figure 6*a*) that we have three atomic 2*p* patterns (dumb-bell orbits *A*, *B*, *C*) on adjacent atoms, and that the three patterns are similar and parallel, and point perpendicularly to the line of atomic centres. We are to make molecular patterns from these three atomic ones. Clearly one way is to link *A* and *B* and so make a molecular pattern such as figure 6*b*, in which *C* is left just as in an isolated atom. But equally clearly there is another alternative (figure 6*c*), where we link *B* and *C* and leave *A* isolated. Nobody can say that one of these is favoured rather than the other. In a word, the two possibilities (*b*) and (*c*), which Pauling calls Valence-Bond Structures, are both equally possible: there is no unique pairing of the atomic electrons.

An extreme case—indeed, the *locus classicus* of the phenomenon—occurs in benzene (C_6H_6). This molecule is known to be planar and in the shape of a regular hexagon, thus:



A pair of electrons is allotted to a sausage-like pattern between all adjacent C–C atoms and between all C–H atoms, thus forming a total of twelve normal single bonds. There still remain the six dumb-bell patterns for an atomic electron around each carbon nucleus. These are shown schematically in figure 7*a*. Now, there are obviously two quite distinct ways of joining these in pairs: in a manner exactly equivalent to that illustrated in 6*b* and 6*c* we obtain the molecular patterns 7*b* and 7*c*. Once again there is no unique way of pairing the atomic electrons, for 7*b* and 7*c* are obviously on an entirely equal footing. The mathematical reasoning of quantum theory now tells us that neither of the two structures 7*b*, 7*c* is by itself a valid representation of the appropriate Schrödinger wave function, but a good approximation is obtained if we suppose that both structures contribute equally to a so-called resonance hybrid. Physically this means that benzene should behave partly as if the double bonds were in the one position and partly as if in the other.

But notice what our mathematics implies. For the two structures 7*b*, 7*c* are precisely what Kekulé introduced as long ago as 1865; and he supposed them to be in dynamic oscillation, interconversion taking place too quickly to be observed. Now we see that the phenomenon described as resonance means that instead of two structures alternating rapidly, we must regard the true situation as a simultaneous superposition of both. The bonds do not alternate between single and double: they are at the same time partly single and partly double, according to the way the electrons are paired. Our mathematics has taken Kekulé's original brilliant intuition and fitted it into a formal, logical, and precise theory. An interesting verification of this point of view is given by the carbon–carbon bond length. On Kekulé's picture this would alternate between 1·54 Ångstroms (single C–C bond) and 1·34 Ångstroms (double C = C bond). According to the resonance theory, in which all bonds are equivalent, it should have



(*a*) (*b*) (*c*)

FIGURE 7 – *Benzene pairings.*

(*a*) *Separate unpaired electron patterns.*
(*b*), (*c*) *Distinct alternative pairings to form molecular patterns.*

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one distinct length between these two. X-ray measurements show it to be about 1·39 Ångstroms.

Before going any farther we can now give a more inclusive definition of quantum-mechanical resonance. 'When the electrons in a molecule may be paired together in two or more structures which are equivalent or nearly equivalent to one another, the actual molecule does not conform to any one of the structures, but is a resonance hybrid of them all, showing at the same time characteristics of each separate structure.'

Why is it called resonance? Historically the name derives originally from the acoustic phenomenon. Resonance can be illustrated mechanically by the familiar physical experiment in which two simple pendulums of nearly equal lengths are swinging side by side suspended from the same taut horizontal wire. If the two natural periods are nearly equal, it is well known that the two separate oscillations interact and are replaced by two combined modes (normal modes) of vibration, in which the energy flows from one pendulum to the other, so that the amplitude of the one decreases while that of the other increases, and then vice versa. The parallel with benzene is very obvious. Each separate pendulum oscillation corresponds to a particular pairing scheme 7*b* or 7*c* which interchanges with the other. In fact, there is a further important comparison, for there are two possible normal modes for the pendulums. One frequency is greater and the other is less than that of the two components. In the case of benzene there are two ways of superposing the structures 7*b* and 7*c*: one has a lower energy than either structure by itself; the other has a greater energy. We call the resonance hybrid with lower energy the ground state, and the lowering of energy as a result of the superposition of the separate structures is called the resonance energy. Other things being equal, the resonance energy is greater the more structures there are combining. In the case of benzene the upper state is important in absorption of light, and the characteristic appearance of the compound is related to the emission or absorption of light when a quantum jump takes place from the one resonance hybrid to the other.

All this is quite general. On the one hand, there is always a lowering of energy as a result of resonance mixing, which nicely accounts for the relatively great stability of compounds like benzene. On the other hand, this is achieved by delocalizing the electrons. In the case of benzene, on account of the superposition of 7*b* and 7*c* an electron originally round atom No. 1 is sometimes paired in a molecular orbit round atom No. 2, so that it can migrate to this atom. In the new position it may be paired with an orbit from atom No. 3, and may thus continue its migration round the carbon ring. Indeed, we might describe the situation by saying that there are six electrons in benzene which are able to flow as tiny currents round the central hexagon. These currents should show characteristic magnetic effects. Without describing them in detail it may be said that these are just what are found experimentally in the diamagnetic anisotropy. This delocalizing of electrons should also mean that any chemical disturbance at one part of the ring should be propagated (with perhaps a diminishing power) to all other parts of the molecule. This is, in fact, the basis of the theoretical explanation of all the inductive and mesomeric effects so fully investigated by experiments in which one atom or group is replaced by another.

These are important applications of the theory of resonance, but they by no means exhaust its utility. There is space briefly to list five others, in which we choose particular examples to illustrate general principles.

FRACTIONAL BOND ORDER; EXAMPLE, NAPHTHALENE

In benzene there are only two important structures. In naphthalene, however, there are three, as shown in figure 8, corresponding to the three different ways of pairing the atomic electron patterns. If all three of these contribute equally to

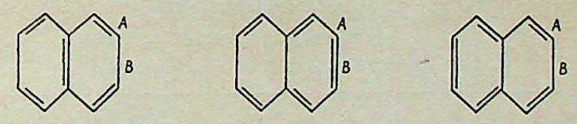

FIGURE 8 – *Three valency bond structures for naphthalene.*

the resonance hybrid (this is not quite accurate, but it is not far wrong), a bond such as that marked *A* would be a double bond for $\frac{2}{3}$ of the time and a single bond for $\frac{1}{3}$. More accurately, it would be described as $\frac{2}{3}$ of a double bond and $\frac{1}{3}$ of a single bond. We might call its order $1\frac{2}{3}$. Similarly the bond *B* should have an order $1\frac{1}{3}$. Clearly *A* would be more similar to a double bond. This fits very satisfactorily with the experimental fact that *A* is more reactive than *B*. But notice that we are now able to assign a numerical (fractional) order to a bond. One result of resonance is to destroy the pure single-bond or pure double-bond

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character of a bond and to replace it by a fractional bond order.

IONIC STRUCTURES: EXAMPLE, THE CARBONYL GROUP

Sometimes resonance is confined to a part of a larger molecule. Thus, if R stands for some large saturated radical (in which resonance is not a very significant factor), the molecule R·COOH is an acid; in solution H^+ separates off, leaving a structure that might be represented by the diagram R–C$\langle^{O}_{O^-}$, in which a free electron is found on the one O atom. But another pairing system would lead to the structure R–C$\langle^{O^-}_{O}$. These are called ionic structures to distinguish them from the previous covalent structures. Evidently there is resonance between the two ionic structures. The resulting resonance energy is one strong reason for the acidic property of the original molecule, for it makes the removal of the H atom (without its electron) relatively easy.

METALLIC CONDUCTIVITY: EXAMPLE, A GRAPHITE LAYER

We have just seen how ionic structures contribute to resonance. Their existence also explains

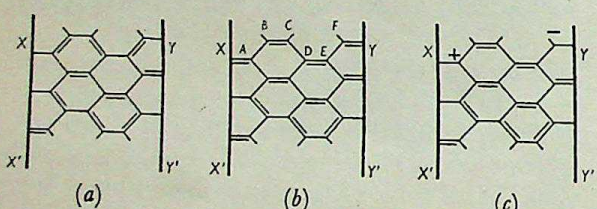

FIGURE 9 – *Bond structures for a graphite layer. (a), (b) Alternative covalent structures. (c) An ionic structure.*

how a metal is able to conduct electricity, i.e. how electrons can move with greater or less freedom over a regular lattice of atoms. Consider in particular a small element $AB \ldots F$ of a layer of graphite, shown in figure 9, in which the carbon atoms are arranged in a regular hexagonal array and which is bounded by the electrodes of a battery at XX' and YY'. We can draw a series of resonance structures to illustrate the pairings of electrons, just as we have already done for benzene in figure 7. Figures 9*a* and 9*b* are two examples from a very large number. Then on account of the alternative electron pairings represented by 9*a* and 9*b*, an electron originally at X can move first to A, then to $B, \ldots$, and finally to Y. So electrons are able to move quite freely through the lattice. The only difficulty is that, so far, whenever one electron moves in one direction another electron momentarily paired with it must move in the opposite direction, so that there is no net flow of charge. To get such a flow we must introduce ionic structures like 9*c*, in which there is an extra electron on atom F at the expense of atom A. Normally this structure will be balanced by another, with the charges interchanged. But in the presence of a suitable electric field c will predominate and there is a partial flow of charge. If the electrodes of the battery are able to collect this charge at YY' and re-issue it to the crystal layer at XX', we can understand why the applied e.m.f. is able to cause a steady flow of current. Ohm's law is therefore bound up with the relative importance of ionic structures such as 9*c*.

CHEMICAL REACTIONS: EXAMPLE, $H_2 + Br_2 \rightarrow 2HBr$

Resonance also enables us to understand what is happening in a chemical reaction. Consider the reaction $H_2 + Br_2 \rightarrow 2HBr$. In figure 10*a* we show the H_2 and Br_2 molecules approaching one another in such a way as to facilitate the conversion to two HBr molecules shown in (*e*). The original interpretation of this reaction, due to Erlenmeyer (1901), was that as the H_2 and Br_2 approached, there came a sudden moment when the bonds switched over and instead of H–H and Br–Br we discovered two molecules of H–Br. But now we see that there is no sudden switching of the bonds: there is a gradual transition. In (*b*) the structure $\begin{matrix} H & Br \\ | & | \\ H & Br \end{matrix}$ contributes more than $\begin{matrix} H–Br \\ H–Br \end{matrix}$. But in (*c*) they contribute equally to the resonance hybrid. This latter situation is sometimes called

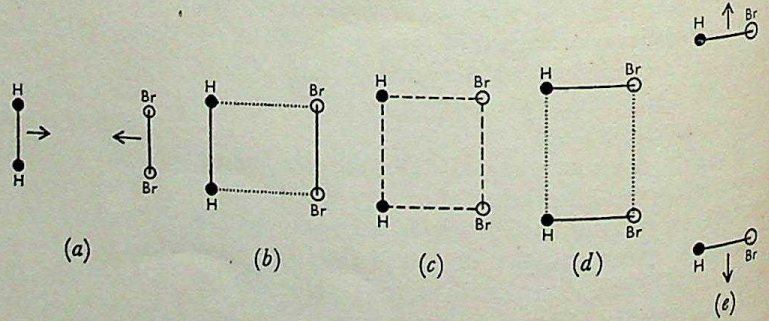

FIGURE 10 – *Successive stages in the reaction* $H_2 + Br_2 \rightarrow 2HBr$.

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the Reaction Complex or Activated Complex: in it the bonds are scarcely localized at all. As the reaction proceeds, in (*d*) the $\begin{matrix}\text{H–Br}\\ \text{H–Br}\end{matrix}$ structure is dominant, till finally in (*e*) two H–Br molecules are existing completely in their own right, and the reaction has taken place.

POLYMERIZATION: EXAMPLE, POLYTHENE

A closely similar explanation can be given for polymerization reactions, so important in the study and development of artificial rubber. Below (figure 11) we show the first stage in the polymerization of ethylene to polythene. As two ethylene molecules (C_2H_4) approach together

(I) $H_2C = CH_2$ $H_2C = CH_2$
(II) --- $H_2C - CH_2$ - - - - $H_2C - CH_2$ - - -
(III) - $H_2C - CH_2 - CH_2 - CH_2$ -

FIGURE 11 – *Stages in the polymerization of ethylene.*

there is a small amount of resonance between the structure (I), with two localized double bonds, and (II), in which the double bonds have been opened up and pairing takes place across the central carbon atoms. As the molecules approach more closely (II) becomes increasingly important, so that we finish with (III), in which the free valency at either end of the chain makes the subsequent addition of more ethylene units at least as easy as the first.

But enough has been said to show the wide application of the concept of resonance. One last question arises: is resonance a *real* phenomenon? The answer is, quite definitely, no. For consider benzene, with its two Kekulé structures 7*b*, *c*. We cannot say that the molecule has either one or the other structure, or even that it oscillates between them. There is, in fact, simply the C–C aromatic bond. Putting it in mathematical terms, there is just one full, complete, and proper solution of the Schrödinger wave equation that describes the motion of the electrons. Resonance is merely a way of dissecting this solution: or, indeed, since the full solution is too complicated to work out in detail, resonance is one way—and that not the only way—of describing the approximate solution. It is a 'calculus,' if by calculus we mean a method of calculation; but it has no physical reality. It has grown up because chemists have become so used to the idea of localized electron-pair bonds that they are loth to abandon it, and prefer to speak of a superposition of definite structures, each of which contains familiar single or double bonds and can be easily visualized. Like most good things, the idea can be overworked, but no-one can deny that in the years since 1933 it has proved extraordinarily successful in correlating, explaining, and even predicting an astonishingly large and varied body of chemical experience.

Book reviews

FRONTIERS OF ASTRONOMY

Frontiers of Astronomy, *by David S. Evans. Pp.* 174, *with* 8 *plates and* 47 *diagrams. Sigma Books Ltd., London.* 1946. 6*s. net.*

Dr Evans has achieved a considerable measure of success in the difficult task of endeavouring to explain in simple terms, which the general reader can understand, some of the problems with which astronomers are concerned today and why solutions to these problems are required. In a slender book, such as this, it is possible to deal only with selected topics and the particular choice of topics is naturally conditioned to some extent by the personal interests of the author. It is therefore perhaps ungenerous to criticize the choice of subject matter. Reference might have been made to some of the unsolved problems of the solar system. It is true that the centre of gravity of astronomical research has moved away from the solar system (the sun excepted), and the reader may conclude that there is nothing more to be learnt. But the problems of the origin of comets, of the nature of the clouds of Venus, of why Venus has no water while the earth has plenty, of the nature of the markings on Jupiter and of the colours of its belts, of the sudden brightening and fading of certain comets, all need solutions and are but a few of the problems of the solar system. The sun's corona is now being intensively studied and undoubtedly holds the key to many solar problems; more might have been said about this and about the magnetic fields of sunspots, which are invariably involved in the production of solar flares. The fact that no mention is made of astronomical investigation by radio and radar — electromagnetic radiation from the sun and the Milky Way giving rise to radio noise, radar reflections from meteors, etc.—is merely a reminder that astronomy advances so fast that any book dealing with its frontiers is necessarily somewhat out of date before it leaves the publishers.

H. SPENCER JONES

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DIFFRACTION BY MOLECULES

The Diffraction of X-rays and Electrons by Molecules, *by M. H. Pirenne, with a foreword by P. Debye. Pp. xii + 160. Cambridge University Press.* 1946. 12*s.* 6*d. net.*

This book deals chiefly with the theory of the diffraction of X-rays and electrons by atoms and molecules, and the use of diffraction methods for the determination of the geometry of simple gas molecules. It is a book about physical principles and methods rather than results. The exposition is admirably clear and concise, and the subject matter will interest not only specialists in the subject but also a wider circle of readers. All X-ray diffraction workers, for instance, will find very useful the earlier chapters on coherent and incoherent scattering, fluorescent radiation, and atomic scattering factors for X-rays; the general reader will be grateful for the discussion of the relative merits of X-ray and electron diffraction methods for studying gas molecules, and will, it is to be hoped, agree with the author's conclusion that both methods should be used for certain types of molecules. If one suggestion may be offered it is this. In Dr Pirenne's book, much less space is given to electron than to X-ray diffraction, although in fact it is the electron method that has been the more widely used of the two for the study of gas molecules. This preferential treatment of X-rays is understandable, because X-ray diffraction is the author's own field of original work, but the book would be better balanced, and would fulfil more adequately the expectations aroused by its title, if the two subjects were treated on an equal footing. Perhaps, however, one should not question a writer's scope, but only sympathize with his difficulty in finding a suitable title for his work. Altogether, this book is a very welcome addition to the literature of diffraction methods.

C. W. BUNN

SCIENCE AND NUTRITION

Science and Nutrition, *by A. L. Bacharach. Pp.* 142. *C. A. Watts & Co. Ltd., London. Second edition,* 1945. 5*s. net.*

The second edition of this book should be as popular as the first. The author has undoubtedly fulfilled his purpose of putting before the reader an account of the methods used in the laboratory for exploring nutritional problems and of the knowledge thereby obtained. He has done it with a simplicity of phrase and use of apt simile that facilitate assimilation. Nowhere does his intention to treat nutrition from the standpoint of the chemist cause him to overlook the nutritional value of substances, even if their chemical complexity be that of the essential oils.

This edition adopts the well-planned arrangement of the first, and incorporates much new material. After a brief account of the form of animal experimentation is a description of the basic constituents of diet: the proteins, fats, and carbohydrates. Two more sections deal with minerals and vitamins. The subject matter is chosen with care and includes only such recent findings upon amino acids, trace elements, and newly isolated vitamins as can be accepted without doubt.

In applying to man the results obtained with laboratory animals the author emphasizes the need for caution. Yet they do suggest that malnutrition in man can arise from a multitude of causes and can be responsible for as much ill-health as infection. As a remedy the author describes in the last section of his book an optimal diet, in the design of which he has combined commonsense with laboratory results; he advocates that all should have the means to obtain it. His book should provide that instruction upon nutrition which will ensure that the means are wisely spent.

J. R. P. O'BRIEN

PRACTICAL CHEMISTRY

Practical Chemistry for Medical Students, *by William Klyne. With a foreword by Professor G. F. Marrian. Pp. xvi +* 460. *E. & S. Livingstone Ltd., Edinburgh.* 1946. 20*s. net.*

It has now become recognized that the education of the future physician must be based on a sound scientific background, particularly as regards chemistry. Within the 460 pages of this excellent book, the author has provided an experimental course of study of an ample and varied character. The book is divided into five parts entitled: Some Fundamental Scientific Ideas, Practical Methods, General and Physical Chemistry, Inorganic Chemistry, and Organic Chemistry. In his preface the author emphasizes that the time allotted to chemistry at Edinburgh does not provide for more than half of the work in the book to be covered. One can only remark that so long as the right choice is made, the interests of the student are amply safeguarded.

Great care has been taken to ensure that the student shall approach his experimental work in the right spirit, not only as regards understanding of theoretical principles, but from the standpoint of care and exactness in carrying it out. But the reviewer is inclined to wonder whether the elaborate list of directions on pages 23–25, concerning what is and what is not to be done in matters of manipulation, could not have been entrusted to demonstrators. Criticism may be directed to some features of the chapter on volumetric analysis, e.g. titration values of less than 10 ml. on page 132, and the omission of the use of adsorption indicators. On page 424 the author refers to Gerhardt's test for aceto-acetic acid. Presumably he means Geuther's test, since Gerhardt died in 1856, and aceto-acetic ester was discovered by Geuther in 1863.

A. J. BERRY

RELIGION AND SCIENCE

The Fourfold Vision, *by F. Sherwood Taylor. Pp.* 108. *Chapman & Hall Limited, London.* 1945. 6*s. net.*

Dr Sherwood Taylor sets out to show that the knowledge and methods of science are not contrary to religion but may indeed contribute thereto. It is an attempt that has been made by many others, with varying degrees of success, but the present essay is devised especially for the scientist, and largely neglects metaphysical arguments familiar to the philosopher and theologian. The main thesis, from which the book takes its title, is that man can achieve four means of apprehension of nature, of which the scientific is but one: first the mere apprehension of diversity without unity; then the perception of the beautiful in nature and its integration in art; next the discovery of harmony in the order of nature through science and philosophy; and finally the apprehension of the world as unified in its orientation to God. Dr Taylor marshals his arguments with great skill and will carry his readers along with him for a certain distance—indeed a considerable distance. But the central problem is perhaps of its nature insoluble, and one cannot help feeling that the book will strengthen the conviction of those already convinced rather than convince those who are not.

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ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

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The role of the scientific society

Progress in all branches of learning is dependent upon the exchange of information between workers pursuing similar lines of study. Such an exchange is of particular importance in science, where the aim is primarily to collect facts and to interpret them in terms of general principles. Science is exceptional in that its interpretation is comparatively little influenced by the opinions of individuals. While theories may need to be revised or even abandoned altogether as new facts are discovered, the facts themselves remain as permanent aids to future workers. The progress of science is therefore essentially a cumulative one, and the modern scientist can normally build his own work on the foundations established by his predecessors. This stability is lacking in branches of learning where interpretation is coloured by personal, national, or political bias. In literature, music, or painting, for example, the accepted standards of one generation may be—and frequently are—scorned by the next.

The progress of science having been so dependent upon the rapid exchange of new knowledge between workers in the same field, scientific societies, of which the main purpose is to facilitate this exchange, have proved of great historical importance. They were formed in some sort almost as soon as experimental science became established. Crafts and guilds for the handing on of technical knowledge from one generation to another are, of course, almost as old as civilization itself, but as their purpose is rather to preserve existing knowledge than to extend it they can scarcely be considered as scientific societies in the accepted sense.

One of the earliest scientific societies of which we have certain knowledge was that of the Ikhwān al-safā', or Brethren of Sincerity, established at Basra about 983, which endeavoured to reconcile Greek science with the Koran. The members discussed scientific, philosophical, and mathematical subjects, and wrote a series of fifty-two treatises which comprised a sort of encyclopaedia. Seventeen of these treatises dealt with natural sciences and fourteen with mathematics and logic. The interests of the Brethren of Sincerity had much in common with those of the philosophers who, centuries later, formed the Royal Society in London. They sought explanations of tides, eclipses, earthquakes, and other natural phenomena, and recognized, for instance, that sound is produced by vibrations of the air, though they could offer no satisfactory explanation of why simultaneous sounds do not mix.

In Europe, the earliest scientific societies were formed in Italy. In 1560 Giambattista della Porta founded the *Academia Secretorum Naturae* at Naples, membership of which was conditional upon making some discovery in natural science. Porta himself made many important physical observations. He recognized the heating effect of light rays and may also have been the first to use a lens in a camera obscura. In 1603 the *Academia dei Lincei* was founded by Federigo Cesi, Marchese di Monticelli. Among its earliest members was Galileo. The *Accademia del Cimento* was founded at Florence by Leopold de' Medici in 1657. It was an institution for experimental research, and though it lasted for only ten years its reports, published in 1667, form a landmark in the history of science. Torricelli and the physiologist Borelli were among the members of the *Cimento*.

In France the *Académie des Sciences* (1666) evolved from the frequent meetings of a group of scientists, including Descartes, Gassendi, and Pascal. This informal club was eventually given official status as a result of the interest taken in it by Colbert, and Louis XIV made grants of money to it and to its members. Later members included Laplace, Buffon, Jussieu, and Lavoisier. The

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Russian Academy of Sciences, founded in 1724, was modelled on the French *Académie*.

In Britain the need for a society for the discussion of scientific matters began to be felt early in the seventeenth century, when the meetings at Gresham College of John Wallis, J. Wilkins, J. Goddard, C. Ent, Robert Boyle, W. Petty, and others resulted in the formation of the Philosophical or Invisible College. From these meetings originated the Royal Society (granted its first Royal Charter by Charles II in 1662), which is today by far the most celebrated scientific society in the world. The Manchester Literary and Philosophical Society, which numbered John Dalton among its many distinguished members, was founded in 1781.

These early scientific societies were representative of science as a whole, for though their members might have a particular interest in physics, chemistry, biology, etc., they were in general natural philosophers with catholic interests. The rapidly increasing extent of scientific knowledge, however, compelled scientists to devote their attention chiefly to one only of the main branches of science. By the end of the eighteenth and the beginning of the nineteenth century, scientific societies appropriate to these specialized interests were being formed. Typical of them were the Geological Society (1807) and the Astronomical Society (1820). In this issue we publish an article on the Chemical Society (1841), which is celebrating its centenary this year after a delay occasioned by the late war. Similar societies were formed on the Continent. The French Chemical Society was founded in 1857 and the German Chemical Society in 1866–7.

The value of scientific societies, as remarked above, lies chiefly in their facilitation of the speedy exchange of new information. Almost from the first they have done this by the publication of scientific papers in their own journals, as well as by arranging lectures and meetings. Today, when scientific work may be pursued along similar lines in many different parts of the world, opportunities for personal contact at lectures and meetings are necessarily insufficient, and the journals published by the scientific societies are correspondingly important. Increasing specialization has brought into existence scores of new scientific societies, studying such specialized branches of science as microbiology, biochemistry, geophysics, and so on. Many of these societies have members in all parts of the world, and though their occasional meetings and lectures are very valuable their main value lies in their journals and other publications, through which all the members can be kept informed of the work being done by their colleagues.

Those scientific societies which have been able to acquire permanent premises have also served a most useful purpose by building up libraries. In them they have gathered together not only complete sets of their own publications but also of those contemporary journals and books which are of value to their members. The libraries of the scientific societies, particularly of those which have been long established, are therefore invaluable to the student. Several of the older societies are also custodians of many articles of historic interest. Besides contemporary portraits of their more distinguished members they often possess manuscripts, apparatus, and personal belongings of the great scientists of the past. Such heirlooms have more than a merely antiquarian interest, for they serve to arouse and nourish the sense of dignity and continuity so essential to the maintenance of high endeavour.

While scientific societies played an important part in the early development of science, today they have become entirely indispensable channels for the dissemination and recording of new knowledge. In common with other learned institutions, many are now encountering financial and other difficulties both in carrying on their existing services and in making the improvements demanded by the present rapid development of science. It should be their policy to maintain a lively and progressive attitude and to discover and fulfil the contemporary requirements of their members. In return it is clearly the duty of scientists to afford the societies not merely financial but also active personal support.

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Atomic energy—threat and promise

R. E. PEIERLS

The physical facts upon which the deliberate release of atomic energy is based are now generally familiar. In the present article, Professor Peierls discusses the potentialities of atomic power, particularly for peaceful uses. He argues that all the applications hitherto suggested amount really to doing better, or more cheaply, things that can also be done by other means. Entirely novel applications of atomic energy will doubtless be discovered when the world has grown more used to the immensely powerful tool now at its disposal.

INTRODUCTION

In public discussion of the prospects of atomic energy, the threat to the future of civilization which the atomic bomb represents tends to overshadow the promise of benefits from the constructive applications of atomic power. After the first public announcements on the bomb, exaggerated claims for the possibilities of an impending 'atomic age' appeared, particularly in the popular press, and the reaction to them discredited the whole subject.

Serious thought about the prospects is, in any case, made difficult by the lack of information, due partly to secrecy restrictions and partly to real uncertainties in the physical, chemical, and engineering data.

In the present article I shall endeavour to appraise the positive possibilities as they appear today, and as far as this is possible within the limits of available information. In many instances it will not be possible to give definite answers, but merely to indicate the factors on which the answers depend and the types of problems that have to be solved before the answers can be found.

It does not seem necessary to summarize the physical facts on which atomic energy is based, since by now a number of simple introductions are available (see page 57).

THE ATOMIC BOMB

In discussing the potentialities of atomic energy it would be futile to ignore atomic weapons, not only because they were the first and, up to now, the only important practical application, but because the threat which they represent must always override all imaginable advantages. If there is to be another world war fought with atomic weapons and, as we have to expect, with other new weapons of mass destruction, prospects are so grim that the constructive applications of atomic energy would give us poor comfort. If, on the other hand, international politics were to progress to a point where we felt reasonably confident that there would not be another major war, this would represent such an enormous step forward that the direct benefits would for a long time appear insignificant in comparison.

This problem is essentially political and outside the scope of this article, but it may be appropriate to summarize here the features of the atomic bomb that make it play such an outstanding part. We have often been reminded that the atomic bomb raids were not the most destructive single operations in the past war, nor the ones involving the greatest number of casualties. The essential new feature lies in the comparative cheapness of these weapons, once the necessary scientific and development work has been done, and in their small bulk, which makes it possible to deliver them by a variety of means against which an effective defence and even an adequate warning system seem quite impossible. As a result of this, once stocks of atomic bombs are available, surprise action becomes much easier than with other forms of attack, which require large operational forces.

It is probably not true that atomic bombs in themselves would make a future war much more destructive. Other destructive techniques were perfected during the recent war, and there is no doubt that such weapons as rockets of the V2 type were only just beginning to play their part. Other new developments, like chemical and biological warfare, about which very little has been said in public, share many of the features of atomic bombs. Attention has focused on the atomic bomb because its effect has been demonstrated.

One of the essential features of atomic warfare is that it is bound to result in heavy damage and casualties to all parties (assuming that both sides possess these weapons) and that, while it may be possible to deliver a crippling blow in a very short time, this will not prevent retaliation striking even

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the country whose stocks of atomic bombs are superior. Hand in hand with that goes the fact that, while they could destroy a country, atomic bombs could not be used to occupy and hold it. Hence they lend themselves to irresponsible destructive action but not to any calculated aggressive war that is likely to benefit the aggressor.

It is important to stress this feature because it indicates that the destructive nature of atomic weapons may itself be of ultimate benefit if it helps to bring home to everyone the lesson that the use of military force for aggression does not pay.

CONSTRUCTIVE USES OF ATOMIC BOMBS

Supposing the threat of atomic warfare could be eliminated, are there any other uses to which atomic bombs could be put? No definite suggestion has so far been made that can bear examination, but the problem is so new that the possibility should not be ruled out altogether. The use for mining and other similar engineering operations would seem extremely difficult, for three reasons. One is the enormous intensity of the blast action in the immediate neighbourhood of the explosion centre, which leads to a much more thorough destruction than is necessary or desirable. This immediately rules out the use in all those mining operations where one is dealing with a narrow vein of ores. One would probably then find the ores thoroughly mixed up with the surrounding matter, and their recovery would be more difficult than before.

The second difficulty lies in the fact that it is very difficult to use atomic explosions in a controlled way and to limit their effects, since in any use underground the range of the blasting action will depend greatly on the nature of the geological structures, which are hard to explore over a region as large as the likely range of the explosion. In addition, the power of atomic bombs is not exactly predictable and will vary somewhat from one instance to another, depending in most types of design on whether or not a stray neutron happens to initiate a chain reaction before the mechanical assembly of the components is complete. Even if the power of the explosion could be made precisely reproducible there would still remain the difficulty that the precise range in different types of rock or soil could be ascertained only by experimentation (as it is with ordinary mining explosives), and such experimentation covering the necessary variety of conditions would be a prohibitive task.

The third difficulty is that in an underground explosion the greater part of the fission products, with their intense radioactivity, would probably remain on or below the ground and that therefore the affected area would become inaccessible for a very long period. This difficulty did not arise in the past because, for explosions in air, most of the radioactivity is carried up into the upper atmosphere, while in underwater explosions it is reduced fairly rapidly by dilution.

In spite of these difficulties, one could imagine cases in which it is not necessary to limit the range precisely. This applies, for example, to breaking a gap in a mountain range so as to alter the course of a river, or to breaking up an ice-pack that threatens to cause serious obstruction. The danger of radioactivity may not be serious where speedy access to the area is not needed or where one can make sure that rising air will disperse the products.

ATOMIC POWER

Leaving aside the very speculative possibility of utilizing atomic explosions, we are left with atomic chain reactions conducted in a controlled way. Their most obvious use lies in the power they generate. From the point of view of basic physics this problem is completely solved, and there is no difficulty in operating an atomic pile in such a way as to generate heat at whatever rate it can be removed from the pile by a suitable cooling medium. Considerable engineering problems remain, however, of which the most serious is the question of reaching a temperature at which the generation of power becomes economical.

The chief reason for this difficulty is that in all piles constructed with ordinary uranium the reproduction factor, i.e. the number of secondary neutrons available to cause further fission for each primary neutron resulting from the previous fission process, is only slightly larger than unity. The chain reaction can, of course, proceed only if this reproduction factor exceeds unity, and any cause that will reduce it by more than the slight available margin will prevent the pile from operating. Such a cause is represented by the absorption of neutrons in impurities, in the cooling medium, or in materials introduced for structural reasons. Hence if we think of piles made of uranium metal and graphite, like the piles now operating at Hanford in North America, we must not only use uranium and graphite of an extremely high degree of purity, with tolerances for certain impurities of the order of a few parts in a million or better, but the amount of water or other cooling medium used in the pile and the

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amount of other materials introduced for structural purposes or for preventing corrosion of the uranium metal must be extremely limited. Because of such limitations the Hanford piles do not permit a temperature-rise that would allow the generation of steam at even a modest pressure. There seems no doubt, however, that a determined attack on the remaining engineering problems will lead to a solution in which the temperature of the pile can be raised considerably. As far as the basic nature of the reaction is concerned, there is no practical limitation to the temperature. There is, in principle, no reason why it should not be taken up to a point where the utilization of the heat by means of steam engines or turbines or any other methods of generating mechanical energy is most favourable. How far this can be carried in practice is as yet unknown, and the higher the temperature the greater the difficulties in protecting the structural components against corrosion or against mechanical distortion. Both problems are accentuated by the presence of intense radiation, which accelerates chemical action because of the high degree of ionization and dislocation of atomic structures that it causes, and which may even reduce mechanical strength.

Some of the problems in the way of high-power piles would be eased if the piles were constructed not of ordinary uranium but of enriched material, obtained either by separation of isotopes or as a result of nuclear transformations carried on in piles of the Hanford type or in the power piles themselves. In this case the active content of the piles is increased, and with it the margin in the reproduction factor. Piles constructed in this way have much more latitude in the use of structural materials and cooling medium, but the corrosion problems remain, and at the same time the piles burn a very much more expensive fuel.

Another difficulty in the operation of all piles is represented by the dangerous radiations, contributed in about equal parts by the neutrons themselves and by the gamma rays resulting from neutron-capture in the pile and from the radioactive fission products. This necessitates heavy protective shields around the piles, and arrangements for doing any adjustments on them by remote control. It also requires arrangements to prevent the escape of radioactive materials by way of the cooling medium into the machinery driven by the pile. Otherwise this machinery would become radioactive and would have to operate inside the radiation shield; it could then not be serviced except by remote control.

Similarly, refuelling of the pile and removal and treatment of depleted fuel have to be carried out by remote control. These obstacles have been overcome in the piles now in operation, but they represent severe limitations in the engineering design.

ADVANTAGES OF ATOMIC POWER

We have seen that, even if not all engineering problems in the way of the production of atomic power have been solved, they at least appear soluble. What will be gained by making atomic power available on a large scale? We shall first consider large stationary power units, used to generate electricity.

The cost of electricity from such stations will depend on the cost of the fuel, the capital charges and running expenses of the pile itself and its auxiliaries, and the cost of generating machinery and distribution. The last item is much the same as for conventional power stations, except that the factors governing the location of atomic power stations are different; this may affect the distribution cost. The pile itself probably represents a much greater capital investment than a boiler plant, though not necessarily a higher running cost. The actual cost is hard to estimate when the design is as yet unknown. Since the pure materials (uranium, graphite, etc.) required for the pile represent a major item, the cost must also depend on the scale on which these are being manufactured, and hence on the overall scale of the atomic power programme.

The cost of the raw material at pre-war market prices is very small compared to that of a corresponding amount of coal. No doubt the applications of atomic energy make uranium a more valuable material, and indeed, because of its military importance, there is presumably no free market for it at all. Even so, quite a considerable rise in the cost of raw material would hardly affect the cost of electricity from such a plant.

These considerations show that, since at present the generating and distribution costs are a large item in the price of electricity, the cost of atomic power is likely to be about the same as for electricity from coal and that, even if we assume the pile to cost no more than a boiler plant and the fuel to cost nothing, the price of electricity would fall by only some 20 or 30 per cent.

A recent official statement by the American authorities confirms these rough estimates, and arrives at a price for electricity that is slightly higher than the current one. A slight increase in the cost of coal at the power station would

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equalize the difference. No details were quoted, but it seems likely that a similar estimate for conditions in Great Britain would show a slight balance in favour of atomic power. These figures are not meant to be precise, and further experience may well show a somewhat greater margin on either side.

It follows that we can hardly expect a revolutionary change in the price of electricity. One specific advantage of atomic power is the small bulk of the fuel consumed, which makes the power stations independent of access to railways and waterways. This allows the planning of power stations close to the consumer, and reduces the difficulties of distribution; it also gives more freedom in placing the stations in positions where the low-grade heat that is always a by-product of the generation of power can be used for heating or for industrial purposes.

This specific advantage is of outstanding importance in the case of countries, such as Italy, in which there are no adequate resources of power and where the transportation of coal becomes an important factor. It may even make possible new projects, such as the irrigation of desert areas in which the supply of power would today present prohibitive difficulties.

In addition, atomic power may add to our resources if and when the depletion of known coal deposits, or lack of people who are attracted to mining as a career, limits the supply of coal. At equal cost, it would surely be preferable to employ fewer men in coal mines. It should not be assumed, however, that atomic power stations may in the immediate future reduce the demand for coal. Even disregarding the time still needed for the necessary development work, it will take a long time to build atomic power stations on a sufficient scale to have any effect on world economy. It will take an even longer time to convert to electricity such things as railways, domestic fires, and so on, the conversion of which would become worth while only if the price of coal were to increase relatively to that of electricity. In any case it must, of course, be remembered that there will always remain some need for coal for metallurgical, chemical, and other purposes.

All these considerations are based on the assumption that sufficient amounts of atomic fuel can be found. The next section will deal with the question of their availability.

SUPPLY OF RAW MATERIALS

From the previous section it is clear that the availability of atomic fuel is a vital question for the success of any atomic power project. It would seem an easy task to estimate the accessible deposits of suitable ores and compare them with the expected demand, but there are a number of factors complicating this issue. Firstly, the only large atomic piles that have so far been operated work with ordinary uranium. Since the major constituent of this is uranium 238, which does not undergo fission with the slow neutrons on which these piles operate, it is only the rare constituent uranium 235 which is consumed in this operation. This represents only 0·7 per cent. of the uranium found in nature. In the course of this operation, however, some of the neutrons are captured in uranium 238 and convert it (through the intermediate nucleus, neptunium 239) into plutonium 239. It is well known that this conversion was, in fact, the main object of the Hanford piles. It has been stated that the number ν of secondary neutrons obtained from each fission process is greater than one (otherwise no chain reaction would be possible) but less than three. Of these ν secondary neutrons from each fission, one must in a steady chain reaction be captured in another fissile nucleus so as to maintain the chain reaction, and the remainder $(\nu - 1)$ will either escape from the surface of the pile or be absorbed in one or the other of its constituents. Escape from the surface can be made small by increasing the size of the pile, but there are unavoidable losses due to absorption in the 'moderator,' i.e. the substance used for slowing down neutrons (which in the Hanford piles is graphite), in the cooling medium, and in the necessary structural elements of the pile. The remainder may be available for absorption in uranium 238 or in other suitable materials mixed into the pile for this purpose. This number is less than $\nu - 1$, and from the published figures is therefore certainly less than two. We thus know with certainty that at most two atoms of plutonium will be made for every atom of 235 burned in the pile, and it is also clear that this is a generous upper limit.

If it were possible to run the pile in such a way that this number were greater than one, the amount of plutonium generated would be greater than the amount of 235 burnt up. If the properties of plutonium were similar to those of 235, this would mean that by leaving in the pile an appropriate fraction of the plutonium so made we could in this way make up for the uranium 235 that was burnt, and such a pile could therefore continue operating until the depletion of

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uranium 238 reduced the rate of production of plutonium. In these conditions it would therefore be possible to burn not only the uranium 235 but a substantial fraction of the uranium 238.

With our assumptions, the condition for this process is that $\nu - 1$ should exceed one, i.e. that ν should exceed two. There is no guidance from published figures as to whether or not this is the case. Actually we have made the assumption that plutonium is about as efficient a fuel as uranium 235; if it differs appreciably, the critical limit for ν may be somewhat different from two. It will, in any case, be increased by the unavoidable loss of neutrons through absorption in other parts of the pile.

Since, as this process continues, we shall be burning plutonium rather than uranium 235, its success will also depend on the value of ν for the fission of plutonium.

Lastly, it is known that a new fissile material can be made by the bombardment of thorium with neutrons, and that this new material, which is an isotope of uranium of weight 233, may also be suitable for a chain reaction. No evidence is available on the merits of this isotope as an atomic fuel compared with uranium 235 or plutonium, or on the number of neutrons emitted in its fission.

It is, of course, conceivable that there may be similar processes as yet undiscovered starting from other raw materials, but this does not appear very probable.

All the above uncertainties in the data make the position about raw materials quite obscure. If it should turn out that in a pile starting with ordinary uranium the plutonium produced will more than offset the consumption of uranium 235, and also that as the pile turns over to consuming plutonium the amount of plutonium produced is greater than that consumed, it will be possible to utilize most of the atoms of ordinary uranium. On the other hand, if this is not possible the material will become almost useless when a substantial fraction of the 235 has been burnt. There is, therefore, an uncertainty of about a factor 100 in the amount of uranium required to maintain a given power output. Alternatively, the reaction can be conducted in such a way that some of the excess neutrons are not absorbed in uranium 238 but in thorium, and if it should turn out that the production of 233 more than offsets the initial consumption of 235 or plutonium and later on the consumption of 233, when this becomes the major fuel in the pile, it may be possible to run the power stations in a way in which ultimately the fuel is only thorium without a continuing consumption of uranium. This would at once add substantially to the supply of raw materials upon which we can draw.

Quite apart from this uncertainty, the amount of uranium that we can expect to be available is hard to estimate. There are at present only a few known deposits containing uranium ore in sufficient concentration to make its extraction profitable, but, even if further surveys should not lead to the discovery of new important deposits, it is well to remember that uranium is a common element contained in many minerals (such as ordinary granite) in very low concentration. No methods have as yet been worked out that would make the extraction of uranium from such poor ores a feasible operation. The concentration of uranium in some poor ores is, however, larger than, for example, the concentration of gold in most ores that are commercially worked for gold, and it is possible that a chemical process could be found which would effectively make this uranium available. This would open up sufficient quantities of uranium for any power programme that is likely to be needed in the foreseeable future.

Evidently the question whether any particular extraction process will make low-grade ores economically interesting depends on the price at which the fuel would make the production of atomic power compete successfully with those from other fuels. At present the price of the raw uranium is quite a small fraction of the estimated cost of atomic power, and a considerable increase in the cost of mining and extraction could be tolerated without altering the picture substantially. The limit depends on the place in which power plants are contemplated, because of the cost of transportation of coal, and on the likelihood of an increase in the price of coal owing to the exhaustion of suitable deposits, and other factors.

We must conclude that, while the uncertainty in all these facts certainly does not allow us at this stage to feel assured that a sufficient supply of atomic fuel can be obtained, it is equally impossible at present to exclude this possibility. It is certainly of sufficient promise to justify intensive study and development work.

MOBILE POWER AND OTHER SPECIFIC APPLICATIONS

Can atomic piles be made suitable for small units to be used in ships, trains, etc.? There are a number of factors which make the operation of small plants uneconomical. The first is the

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critical size. It is known that for each reacting system there is a least size at which chain reaction becomes possible, since for any system of smaller size the number of neutrons lost by leakage from the surface reduces the reproduction factor below the critical limit. In the ordinary pile made of uranium metal and graphite we have already seen that the margin in the reproduction factor is very small. Hence only a small leakage of neutrons can be tolerated, and the least size of plant becomes very substantial. If one desires a power unit with a small power output, the plant will still have to be at least of the critical size and will therefore be very bulky. In addition, the amount of atomic fuel locked up in such a power unit is then very substantial, and the unit therefore represents a relatively large capital investment.

Things are more favourable if one can use concentrated atomic fuel, i.e. either uranium 235 obtained from a separation plant, or plutonium, or possibly uranium 233 from thorium. In the case of these substances the reproduction factor is considerably larger, and this brings the critical size down to quite a convenient magnitude. In fact, it is likely that in practice the size of such a unit would be determined by the requirement of getting in the necessary amount of internal surfaces for heat-extraction purposes. On the other hand, such concentrated fuels are very much more expensive. In the case of uranium 235 this would have to be produced by an isotope separation plant of the type of the plants that produced the material for one variety of atomic bomb, although the degree of separation need not be the same as that suitable for the bomb. Plutonium and uranium 233 are produced in piles, and their cost depends essentially on the considerations referred to in the previous section. If it turns out that a suitable pile can not only regenerate the fissile material necessary to keep the pile in operation, but also leaves something to spare, it might be comparatively easy to get fissile materials as by-products of power production.

Even for piles with enriched fuel, however, there remains the need for protective shielding, and it has been estimated that the minimum weight of such a shield is about a hundred tons. This clearly at once rules out use in cars or trains, but a weight of this order is quite modest if one thinks of its use, for example, in a large ship. In fact, it would appear possible in the case of a ship to use the surrounding water as part of the shield and thereby further reduce the deadweight that has to be carried. Whether atomic ships are a practicable proposition is therefore merely an economic question. In comparing the cost of atomic power with coal or oil one has to bear in mind that ships would have to use concentrated atomic fuel, as it does not seem likely that a power unit of the size, say, of the Hanford piles would be suitable for a ship. It is impossible to estimate at the moment the cost of the concentrated fuel. On the other hand, it is certainly an advantage that the weight of the fuel consumed during the voyage would be quite negligible, and this factor would be particularly important for long journeys without refuelling.

As regards aeroplanes, the need for a heavy shield is certainly a most serious handicap, and atomic planes cannot be practical unless one increases by a large factor the overall size of the plane and, with it, the size of the runways, etc. Even if one is prepared to do this, one would probably not want to operate the power unit of a plane on low-grade heat, which would necessitate the use of steam engines. The solution of this problem is therefore dependent on raising the temperature in the pile to a level where more modern forms of conversion to mechanical power become possible.

On the other hand, the low weight of the consumed fuel is in this case a most important consideration, and if an atomic plane is possible at all it will have a practically unlimited range without reduction of the carrying capacity.

A particularly interesting problem is that of using atomic energy in rockets for interplanetary travel. If one looks at this problem purely from the point of view of the balance of energy, it is clear that atomic power overcomes the major handicap of other such rockets. The energy necessary to carry a certain amount of ordinary fuel beyond the range of attraction of the earth is greater than the energy obtained by burning the fuel, whereas for atomic fuel it forms a negligible fraction. However, rockets operate on the recoil produced by ejecting the combustion products backwards, and, since the mass of the combustion product is negligible in the case of atomic power, such rockets would have to carry material specially for the purpose of ejecting it. Thereby one loses all the advantage of the low fuel weight, unless it is possible to eject materials at a speed in excess of that of the combustion products in ordinary material. This means that one would have to use atomic power for heating a suitable substance to a temperature higher than the flame temperature in ordinary rockets. Though there is

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nothing to prevent this in the basic process of a chain reaction, the engineering difficulties are clearly formidable.

RADIOACTIVE ELEMENTS

To return from speculation to well-established fact, we next consider the uses of radioactive elements produced in piles, either as fission fragments or by the neutron bombardment of almost any substance. These can be used for most of the purposes for which naturally radioactive elements have been used in the past, such as medical therapy and industrial radiology, but they are becoming available in practically unlimited amounts, and with a much greater variety of properties. A doctor can, for example, choose for his treatment a radioactive element of a suitable lifetime and can thus inject it close to the affected spot. The decay of the activity will then limit the total dose. At the same time there is more freedom in the choice of the hardness of the radiation. By choosing a radioactive isotope of a suitable element it may be possible to cause the radioactivity to accumulate in a suitable place in the human body, and this principle has been successfully applied in the United States to the treatment of a rare form of thyroid disease by means of radioactive iodine.

In radiology, gamma rays may for certain purposes be preferable to X-rays because of their greater penetrating power, and because they allow the use of a very compact source which may, for example, be placed inside a small opening insufficient to house an X-ray tube. Atomic piles can produce such sources with intensities greatly in excess of those practicable with radium.

A much more important application, however, lies in the use of radioactive tracers for chemical or biological research. This gives the possibility of labelling certain atoms and recognizing them afterwards, while allowing them to take part in a chemical or biological process in which their history will be precisely the same as that of other atoms of the same element. This allows us to recognize, for example, the exchange of two atoms of the same element between two different molecules, and it allows us to identify the origin of substances in a living body—to see, for example, whether they are taken up as part of the current food intake, or whether they come from deposits of the same substance in other parts of the body. Such tracer methods were already being employed before the war, using radioactive isotopes made in the laboratory by means of cyclotrons or other machines. Atomic piles provide both greater quantities and greater variety.

A further advantage of such tracers is that their radioactivity may make it possible to observe them in the living body, while keeping the intensity of radiation well below the safe tolerance limit. It is immediately evident that this method of studying chemical reactions in the living body is an extremely powerful tool.

Similarly, there are applications of such tracer elements in other fields, notably in engineering research. These possibilities have not yet been adequately explored.

The amounts required for such experiments are usually quite small, so that a pile which, as a power station, has a very modest output can keep a number of laboratories supplied. In the United States such radioactive tracers are already freely available, but their export is prohibited by Act of Congress. In England work is in hand on the construction of a pile for this purpose.

OTHER POSSIBILITIES

All the applications discussed above amount really to doing better, or more cheaply, or more conveniently, things that could also be done by other means. Nobody has so far shown enough foresight to say what completely new uses may be found for atomic energy. Similar reasoning applied to the steam engine or to electricity or to the internal combustion engine, when they were first introduced, would evidently have given a very incomplete picture of their promise. It may well be that the really important applications will not be thought of until the world has got more used to the new possibilities.

However that may be, I hope to have made it clear in this necessarily vague and incomplete report that a great wealth of new possibilities is opened up by atomic power, and that, if we show enough enterprise and determination in exploring them, they are bound to add materially to the resources of the world.

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The Royal Botanic Gardens, Kew

SIR EDWARD SALISBURY

'Kew Gardens' are famous the world over: to the layman as one of the sights of London, and to the botanist, horticulturist, and arboriculturist as their own particular Mecca. The four main divisions of the institution, namely the living collections, the herbarium, the museums, and the research laboratory, together form an unrivalled instrument for the recording and expansion of our knowledge of plants and plant products. Sir Edward Salisbury, the present Director, describes the Gardens and their main service to the study of vegetable life.

The Royal Botanic Gardens at Kew are an institution that, in a typically English way, had its origin in private enterprise. The initiative dates back to some 180 years ago, when Princess Augusta (mother of George III) began to form a botanical collection which the acumen of Sir Joseph Banks quickly raised to the first rank of importance. Even so, the collections declined in the early years of the nineteenth century and might have been lost as a national asset had it not been for the report of Lindley, the first Quain Professor of Botany at University College, London. Now, more than a century later, another Quain Professor has become Director. The Gardens as we see them at the present day owe much of their planned beauty to the first two directors, Sir William and Sir Joseph Hooker. The Hookers were followed in turn by Sir William Thiselton Dyer, Sir David Prain, and Sir Arthur Hill, each of whom effected further improvements.

The extent of the Gardens today is some three hundred acres—a far larger area than the original garden—and it is because a second garden was joined to the first that the plural still persists in the official title. Many of our countrymen in Britain are rightly proud of Kew, but its real value is probably more appreciated, and for better reasons, by our kith and kin overseas than by those at home. The latter too often regard Kew as an especially attractive public park, and though its value as a summer resort amid floral beauties must not be underrated, yet the wider recognition that this aspect is but a by-product of its real function might perhaps induce a greater and more intelligent regard for the specimens it contains.

The number of living species which are here cultivated is quite remarkable, and it is a tribute alike to the horticultural skill of the garden staff and to the adaptability of the plants themselves that even in the open there are to be seen many thousands of species culled from the most diverse regions and soils. In the Temperate House, probably the largest glasshouse in the world, over an eighth of a mile in length, are to be seen the Acacias and Epacrids of Australia and New Zealand; the Camellias of Japan; a wonderful display of Tree Ferns, Rhododendrons from the Himalayas and Java; the marvellous pink blossoms of *Magnolia mollicomata*; and the flamboyant blooms of Tibouchina from tropical America. Or we may walk over to Decimus Burton's masterpiece, the great Palm House, so well proportioned that its great size—more than 360 ft. long and 66 ft. high—is but half realized. Here a collection of Cycadaceae gives us some faint idea of what the vegetation of the earth must have looked like in Jurassic times, when plants of this affinity were an important feature not only in the tropics but elsewhere.

Here too we see the Screw Pines, and tall Palms striving to push through the roof. Or again we go to the Tropical Fern House and see Giant Ferns on the one hand and on the other the puny modern descendants of the giant Lycopods that formed so marked a feature of Coal Measure forests. Then, having thus paid tribute to the outmoded fashions of plant life that achieved their zenith in former epochs, we wander out into the Arboretum, where thousands of species of dicotyledonous and coniferous trees represent the dominant types of the arboreal vegetation of the present day.

All these collections of living plants, comprising more than forty thousand species grouped to please as well as to enlighten, are but a part of the mechanism that Kew provides for the accurate naming of plants and the growth of knowledge of the vegetable kingdom. Indeed, the living collections form a supplement to the Herbarium housed in the extensive buildings to the north of the main entrance, where more than five million specimens are preserved—a vast collection in which the

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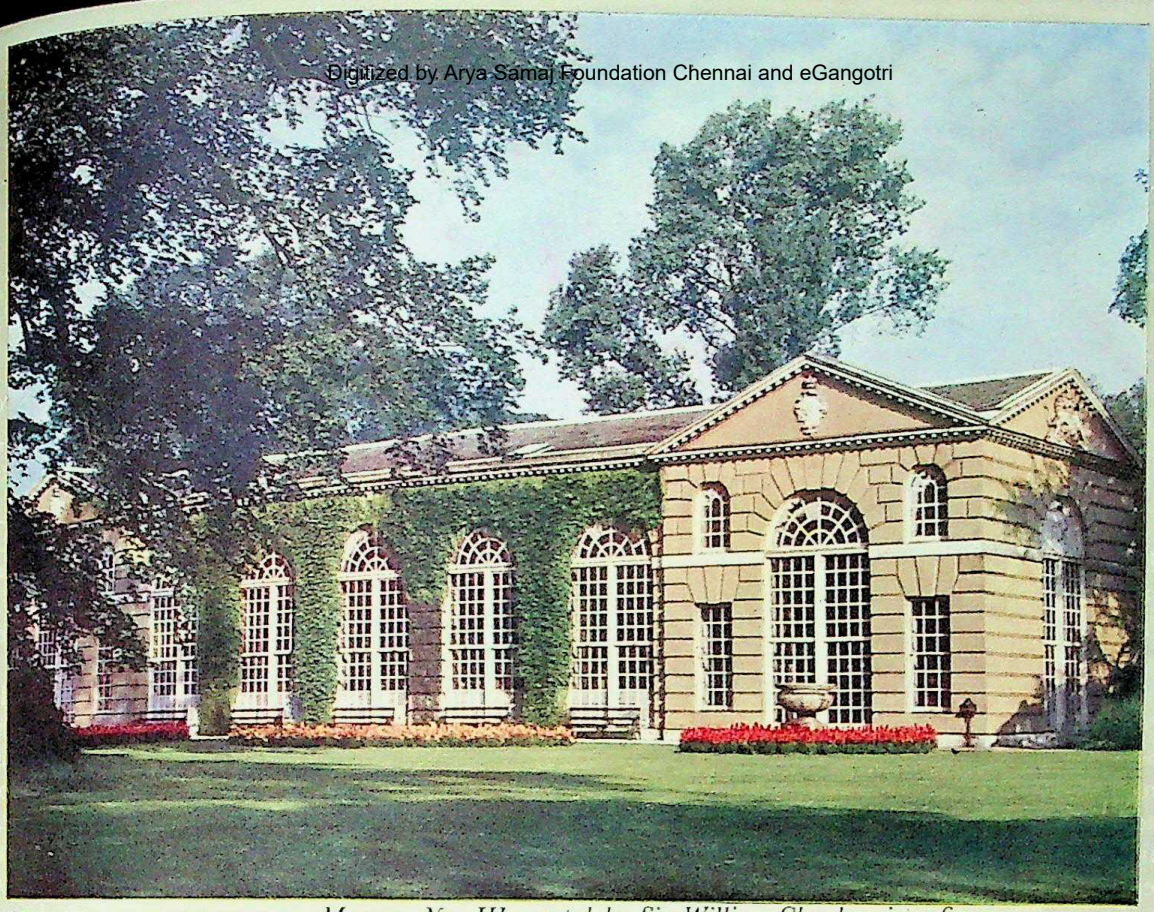

FIGURE 1 – *Museum No. III, erected by Sir William Chambers in* 1761.

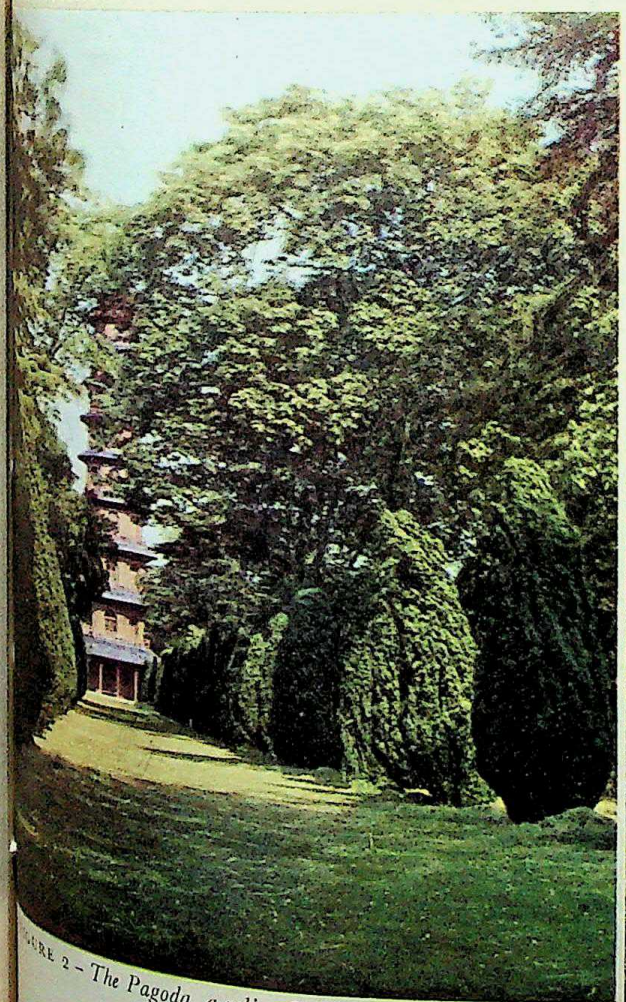

FIGURE 2 – *The Pagoda, a relic of the Oriental phase* (1761).

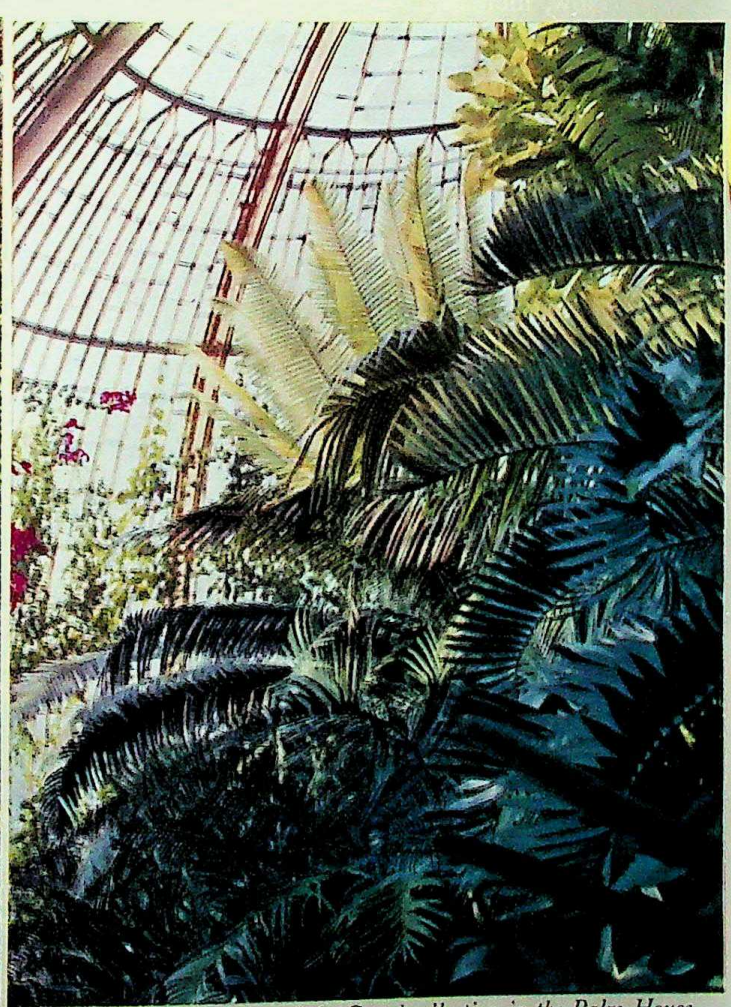

FIGURE 3 – *A glimpse of the Cycad collection in the Palm House.*

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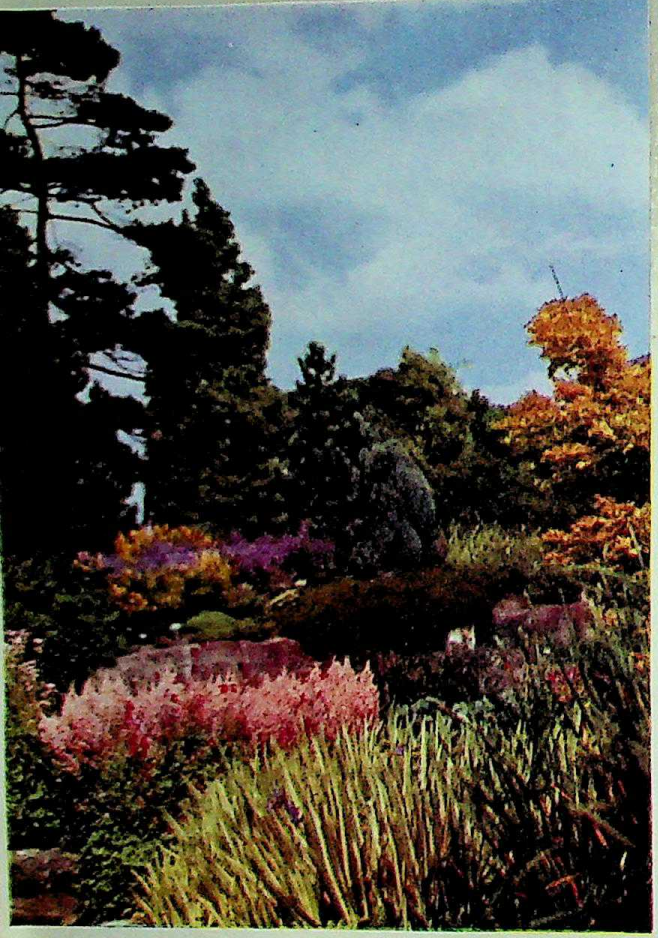

FIGURE 4 (*above*) – *Rhododendrons and tulips in the Broad Walk.*

FIGURE 5 (*left*) – *Part of the Rock Garden.*

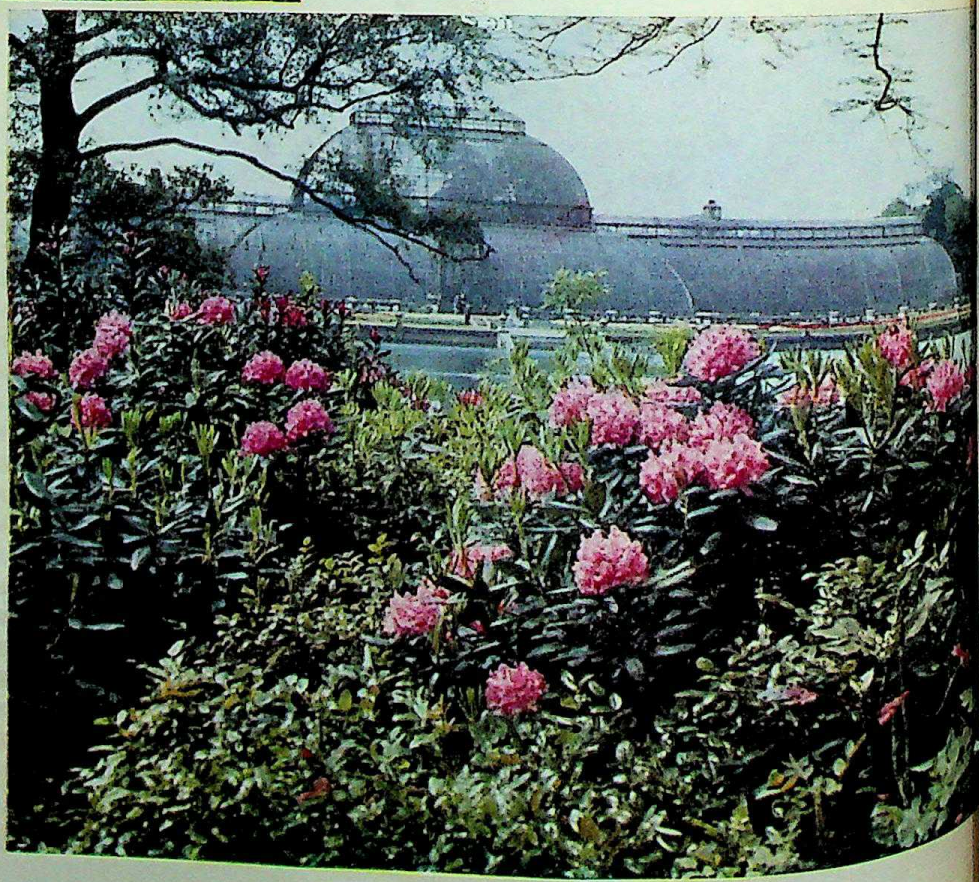

FIGURE 6 – *The Palm House, Decimus Burton's masterpiece, erected* 1844–8.

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proportion of types, co-types, and paratypes is incomparably high. For this reason the Kew Herbarium far surpasses in importance any other collection of such a cosmopolitan character in the world. Hence it is that Kew is the taxonomist's Mecca, and systematic botanists from all over the world are, in normal times, to be found carrying out research within its walls. Naturally, the Kew collections are especially rich in types from the British Empire, and Kew has thus been the source of production of a long series of Floras, from the famous *Flora Antarctica* and the Flora of British India, published between 1872 and 1897, which treated of some 14,000 species, to the Flora of tropical West Africa, which appeared just before the recent war. Here too is produced the *Index Kewensis*, in which are enumerated the Latin binomials of all flowering plants, with references to the source of the original description. Every five years a supplement is issued to include all newly described plants in this category. The whole constitutes an indispensable tool for all botanical taxonomists. Much of the knowledge and experience of Kew in respect to the taxonomy of particular regions is embodied in the series of floras already referred to, and in numerous monographs of particular families or genera. The Herbarium with its large library is in fact an extensive taxonomical research institute, where a permanent staff and visiting scientists are continually advancing our knowledge of the world's flora.

The *Kew Bulletin of Miscellaneous Information* is the means of recording much of the more-specialized research that is carried on at Kew alike in the fields of pure taxonomy, plant morphology and anatomy, economic botany, and botanical exploration, and it is a matter for concern that the destruction of the stocks of this periodical by enemy action precludes our meeting the numerous demands for copies that we have received from all over the world.

In the Jodrell Laboratory, research work of an experimental character is carried on, and this laboratory is also the department of the gardens concerned with anatomical investigation. Here has been produced a new taxonomic account of the anatomy of dicotyledonous plants, to be published by the Oxford University Press in the near future. This will embody the information contained in the English edition of Solereder, in preparing which Dr Boodle (late Keeper of the Jodrell Laboratory) played so large a part, together with the mass of information accumulated during the past forty years. It was in this laboratory that the classical physiological experiments of Brown and Escombe were carried out, that D. H. Scott did most of his work on fossil plants, and that during the war the possibilities of rubber production from the dandelion (*Taraxacum kok-saghys*) in English conditions were assayed. Here, too, methods of propagation by growth-promoting substances and taxonomic cytology have been studied. Like the Herbarium, it furnishes accommodation for visiting scientists working on the plant material Kew can so richly provide.

Four museums of Economic Botany in different parts of the Gardens house the extensive collections of plant products. They provide not only an indispensable means of reference for the multitudinous inquiries that come in from all parts of the globe, but act as a valuable source of research material. The vast collection of fibres, timbers, drugs, and food products, both in the raw state and in manufactured form, is here to be found arranged on a taxonomic basis.

Thus the four major divisions of the organization of the Institution, namely the Herbarium, the living collections, the Museums, and the Jodrell Laboratory together constitute a powerful instrument for research and information concerning the identity and characteristics of plants and their products.

But while the living collections are of first importance as a supplement to the *hortus siccus*, they play, and indeed have long played, a most important role as a source for the distribution of economic species throughout the Empire. The part which Kew played in the initiation of plantation rubber and the cinchona industry is too well known to need reiteration. Kew was also responsible for the dissemination of cocoa and oil palm to West Africa, of pineapple to a number of areas, of the nut *Macadamia ternifolia* to Hawaii, and more recently of the oil-producing tree Aleurites to various Dominions and Colonies. These are but a few examples of the extensive plant distribution which has been rendered possible by the skilled use of the Wardian case. In connection with banana-research in the West Indies, Kew functioned not only as a distributing agency but also as a quarantine station. This latter aspect has gained added emphasis with the increased importance of virus diseases, for unless plants carried from one part of the world to another are healthy their distribution may be a menace rather than a service.

The vast numbers of visitors to Kew every year are a testimony to its great popularity as a resort,

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and though for many the Gardens are but a beautiful amenity, they provide for many others a permanent horticultural display where newly introduced or rare species can be seen by the botanical student, the research worker, and the professional or amateur grower. The three stout volumes of *Trees and Shrubs Hardy in the British Isles* by W. J. Bean, a former Curator at Kew, is a gardening classic that embodies much of the cultural lore that has been accumulated during the passage of years. Another such is *The Botanical Magazine*, which was started by William Curtis,[1] but for more than a century has been edited at Kew and contains coloured illustrations and descriptions of new or noteworthy species. It will be realized that the cultural experience of more than a hundred years which has been amassed at Kew enables it to serve as an unusually well-equipped training-ground for horticulturists, and many former Kew students now occupy positions of importance the world over. Moreover, the wide range of material which the gardens can furnish is constantly drawn upon for research in many fields of scientific activity.

Almost every post brings requests for such material. It may be to test the active principle of some plant alkaloid, to investigate the chromosome number of a suspected polyploid, or to compare the epidermal characters of a living Cycad with those of a Jurassic prototype. It is needless to say that, owing to limitations of space and staff, Kew cannot attempt to supply educational material in the broader sense, but in so far as its resources are required for genuine research these are placed freely at the disposal of investigators in universities and other recognized institutions of higher learning—as far as is consistent with the proper maintenance of the collections. The intercourse with overseas botanists is now a highly prized tradition, and it is pleasant to record that though wartime conditions diminished this activity they never caused it to cease, and that it is already being resumed.

The original Botanic Garden was only about nine acres in extent and remained little more until shortly after 1840, when, during the first directorship under Sir William Hooker, most of the present land was added. The only substantial extension since that period was the area of thirty-seven acres presented by Queen Victoria. This comprises the Queen's Cottage grounds, which, as they were left with the proviso that they should remain more or less in a wild state, cannot be appropriately used for planting other than native species.

The area thus acquired a century ago seemed ample—hence the lavish expenditure of space on multiplication of the same species in avenues and in other ways. Since that time the vast influx of species, from both the Old World and the New, has, especially so far as trees are concerned, strained the limits of Kew severely, and at the present time an appreciably larger area would be more than welcome, whilst the glasshouses are now far from adequate.

The Palm House took four years to construct and was completed in 1848. The Temperate House was erected some ten years later and, like most of the glasshouses at Kew, is now too small to meet present needs, despite the fact that it occupies about three-quarters of an acre. Both these houses suffered from enemy action during the late war, a large proportion of the glass of the Temperate House being broken when a heavy bomb exploded in the fork of a near-by beech tree. It is a tribute to both the skill and the devotion of the staff that the resultant losses in plants were much smaller than expected. The Orchid Houses, enriched by gifts from the collection of Sir J. Colman, now contain a remarkable collection of orchid species. The remaining houses contain collections of economic species of tropical and temperate ferns and insectivorous plants, whilst for the general public the *Victoria regia* House, where this giant annual species flourishes, is perhaps the greatest attraction after the conservatory devoted to decorative plants.

Out of doors, the 'order beds' provide valuable material for students, while most of the shrubby and arboreal species are also grouped taxonomically. A recent departure from this tradition has been made, in the interests both of efficient culture and of educational value, by the establishment of a chalk garden.

The different parts of Kew exhibit a variety of styles in landscape gardening, but fortunately, as befits a botanical garden especially, the English style, which we owe in considerable degree to the influence of Kent, Sir W. Chambers, and Pope, who lived at Twickenham, is that which preponderates. Thus so far as conditions permit the ideal aimed at is the display of the natural growth and habit of the species concerned, and indeed the motto of Kew might well be 'Science and Beauty.'

[1] See ENDEAVOUR, Jan. 1946.

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The Chemical Society (of London) after one hundred years

C. S. GIBSON

As the oldest society of its kind in the world, The Chemical Society (of London) will find no one to quarrel with its proud assumption of the title 'The Chemical Society' *tout court*. For over a hundred years its Officers and Fellows have blazed new trails in the advancement of chemical knowledge, the reputation of the Society ranking second to none among chemists the world over. This year the Society officially celebrates its centenary—the celebrations should have been held in 1941, but were postponed owing to the war. We congratulate the Society on this happy and auspicious occasion, and wish it a long-continued vigorous life.

In 1938 H.M. King George VI became Patron of The Chemical Society (of London), and the Council began to take steps for the celebration of the centenary of the Society in 1941 by appointing Organization and Executive Committees. At the Ninety-eighth Annual Meeting in 1939, Sir Robert Robinson, F.(now P.)R.S., Waynflete Professor in the University of Oxford, became President, and it was hoped that he would preside over the Centenary Celebrations to be held in April 1941, which were to be followed immediately by the Eleventh International Congress of Chemistry.

Such arrangements as had been made by September 1939 had to be put on one side, and, for example, the formation of an Advisory Chemical Research Council was deemed to be far more important in the national interest than any further immediate consideration of arrangements for the celebration of the centenary of even the oldest chemical society in the world.[1] Sir Robert Robinson was, indeed, the President at the Hundredth Annual Meeting in direct line of succession to Thomas Graham, F.R.S., President in 1841. In the Centenary Presidential Address, Sir Robert Robinson, after recalling some of the earliest details of the Society and the ever-to-be-remembered services to chemical science rendered by Thomas Graham and Robert Warington, the first Honorary Secretary, as the real founders of The Chemical Society,[2] made the following statement:

> The present is no time for festive occasions, for reunions with our distinguished Honorary Fellows, for international intellectual co-operation generally, and certainly not for an organized scientific congress. Therefore the Council has decided to postpone our Centenary Celebrations, which must be compounded of all these elements after the war. This decision has no negative qualities but is a positive affirmation of our intention to organize as soon as possible an occasion worthy of the Society's splendid record and high position among the academies of the world.

Professor J. C. Philip, F.R.S. (Honorary Secretary 1913–24, Councillor for nine years, Chairman of the Bureau of Chemical Abstracts for the first nine years, 1923–32), succeeded Sir Robert Robinson as President. Few have served the Society more faithfully and efficiently than Professor Philip, and his death after only four months as President was a severe loss. He had undertaken the writing of the Centenary History of the Society; this will be completed by Professor T. S. Moore, who, as Honorary Secretary and Chairman of the Publication Committee, has already placed the Society greatly in his debt. As President, Professor Philip was succeeded by Dr W. H. Mills, F.R.S. (Cambridge). It fell to the next President, Professor W. N. Haworth, F.R.S. and Nobel Laureate (Birmingham), to

[1] Justus von Liebig's personal inspiration played a substantial part in the founding of The Chemical Society; and it is significant that the German Chemical Society was founded in 1866, the year after the return to Germany of A. W. von Hofmann, F.R.S. (President, 1861–3) from this country. The Chemical Societies in other countries were founded as follows: France (1857), Russia (1868), America (1876).

[2] The Society was formally constituted as 'The Chemical Society of London' on 30th March, 1841. The designation was changed to 'The Chemical Society' when the Royal Charter was granted in 1848. Nevertheless, according to the records, the Jubilee of 'The Chemical Society of London' was celebrated on 24–25th February, 1891, under the Presidency of Dr W. J. Russell, F.R.S. Among the names of those present at the Jubilee Banquet is that of Mr W. P. Wynne. Happily, Professor W. P. Wynne, F.R.S., is still a Fellow of the Society, to which he has rendered most notable service as Honorary Secretary, Editor, Councillor, and President (1923–5).

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lead the Society through the last year of the war period and for one year during the aftermath. Professor (now Sir Norman) Haworth, with his Honorary Officers and Council, although occupied with many difficult problems confronting the Society, began at once to continue the preparations for the celebration of the Centenary, which he announced would be held in London in July 1947, and would be followed there by the Eleventh International Congress of Chemistry.

The celebration of the Centenary of the Society thus falls in the second year of office of the present and fifty-sixth President, Professor C. N. Hinshelwood, F.R.S., Dr Lee's Professor of Chemistry in the University of Oxford. Sir Robert Robinson became President of the Royal Society in November 1945, and is, after Sir William Crookes, O.M., D.Sc., F.R.S. (President 1887–9), the second Past-President of The Chemical Society to assume the most important office in British science.

The Chemical Society was inaugurated in the rooms of the Royal Society of Arts, and for nearly eight years continued its meetings there. After the Society had been granted its Royal Charter the Council decided that the possession of its own rooms would be more in keeping with its newly acquired dignity. From then until 1857 the Society had its rooms at various addresses, at none of which did it remain as long as at the Royal Society of Arts. There are indications that The Chemical Society in those days quickly ceased to be popular with its landlords, because the Fellows making communications persisted in carrying out experiments, frequently attended by the emission of divers odours, in inadequately ventilated rooms. In 1857 The Chemical Society, with the help of the Royal Society, was allotted by the Government a meeting-room and a library room (furnished by the private subscription of the Fellows) in Old Burlington House. The present apartments in (New) Burlington House, built by the Government to accommodate the Royal Academy, the Royal Society, and certain chartered scientific societies, were allotted to The Chemical Society in 1873–4. This accommodation has not been extended for more than seventy years.

The Fellows of The Chemical Society are proud of their home—it houses so many treasures, busts, medals, and pictures illustrative of progress in chemistry and of chemists in many parts of the world. At the same time they have recognized its painful inadequacy for many years. The Library and its annexe on the top floor have had to be modified to provide for the largest chemical library in Britain. In 1873–4 the library consisted of some three thousand volumes, whereas new accommodation has had to be contrived for some fifty thousand volumes. Every room in the building with the exception of the meeting-room —and that may have to be pressed into service— has had to be fitted with shelves and racks, and in some places the latter are so close together that it is difficult to move between them. Literally every inch of space is used for the continually growing collection of books and periodicals. Part of the Society's collection of its own periodicals is stored in various places outside. The accommodation may have been adequate for the 733 Fellows in 1874, but the membership is now over seven thousand, and the Library is also used by members of other societies.

On the first floor is the meeting-room, which accommodates 157 persons. As one may suspect, it is often totally inadequate for the meetings of The Chemical Society and of other societies which have met there for many years. The room has a certain dignity. Behind the demonstration table is the presidential chair, bearing the arms of the Society. On the wall above the presidential chair is the unique painting of Thomas Graham, the honoured first President.[1] On the walls are portraits of all the past Presidents, but unfortunately there is now insufficient space for them to be displayed worthily.

When the Society is in session, the mace is placed before the President or his deputy. The mace was presented to the Society in 1930 by Mr A. H. Hooker. After their election, Fellows are formally admitted at all Ordinary Scientific Meetings and sign the Obligation Book, which contains the signatures of all formally admitted Fellows since the foundation of the Society. The earliest signatures are those of Robert Warington and Thomas Graham.

By the entrance to the meeting-room is the 1914–18 War Memorial to Lt.-Col. E. F. Harrison, C.M.G., and to the twenty-nine other Fellows who died on service. Col. Harrison rendered conspicuous service to the nation by his intense, self-sacrificing energy and his wonderful success in equipping the troops with protection against

[1] This portrait was painted in 1931 from a daguerreotype (in the possession of Dr Alexander Scott, F.R.S., President 1915–17). The artist (Mr W. A. Budd) experienced no difficulty in depicting faithfully the features of Graham; he was, however, anxious to have a model for the rest of the picture. Professor G. A. R. Kon, F.R.S., was the suitably dressed model.

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FIGURE 1 – *The mace of The Chemical Society.*

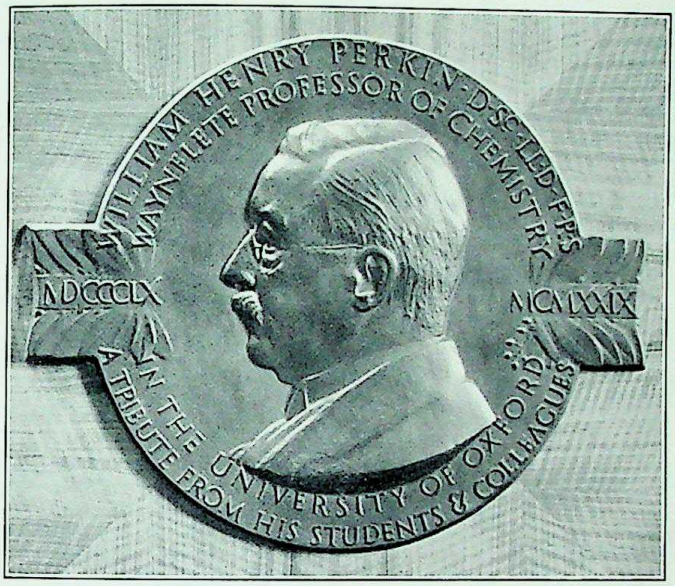

FIGURE 2 – *Professor W. H. Perkin, M.A., Sc.D., LL.D., F.R.S. President* 1913–15.

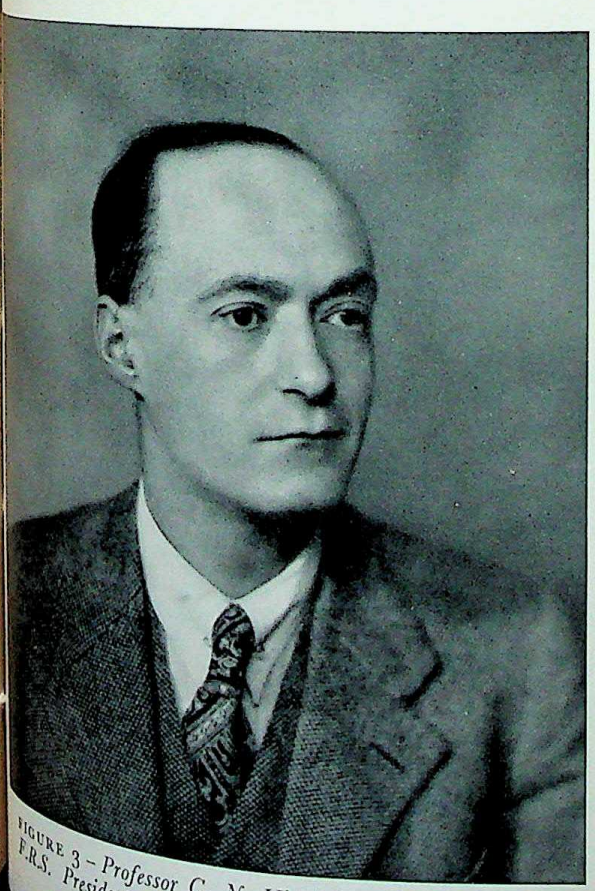

FIGURE 3 – *Professor C. N. Hinshelwood, M.A., Sc.D., F.R.S. President* 1946–

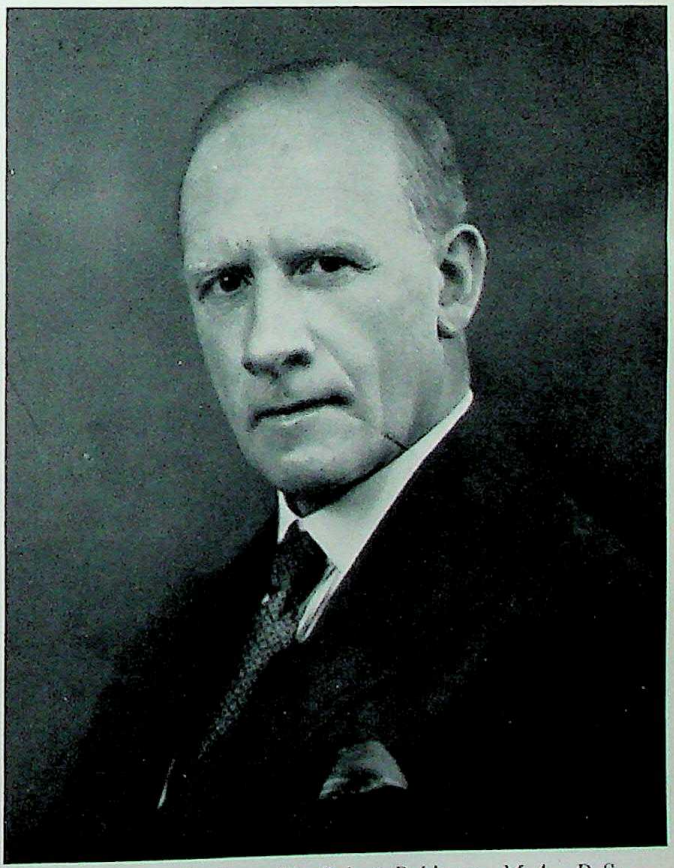

FIGURE 4 – *Prof. Sir Robert Robinson, M.A., D.Sc., LL.D., P.R.S. President* 1939–41.

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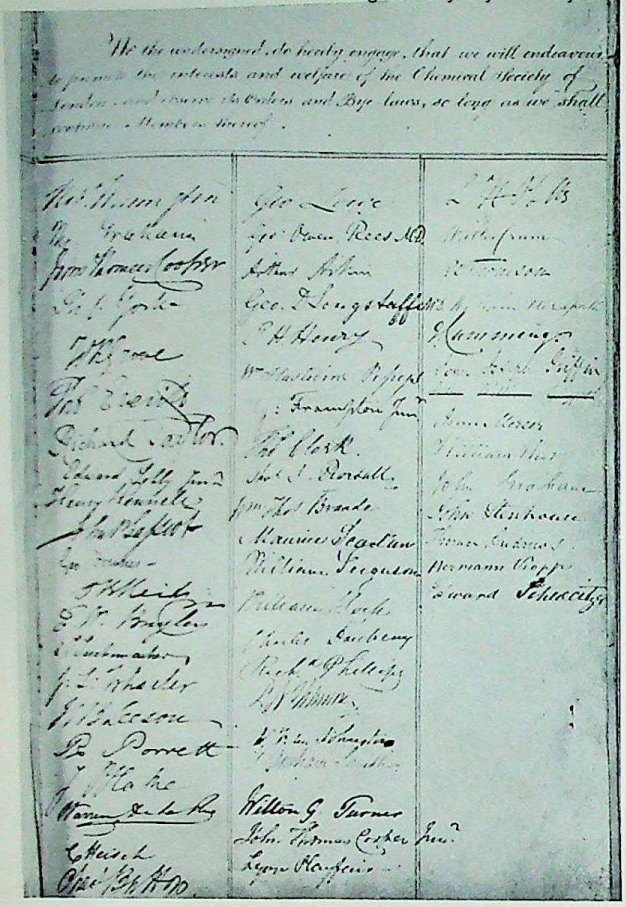

We the undersigned do hereby engage, That we will endeavour to promote the interests and welfare of the Chemical Society of London, and observe the Orders and Bye laws, so long as we shall continue Members thereof.

FIGURE 5 – *The first page of the Obligation Book, bearing as its first signatures the names of Robert Warington and Thomas Graham.*

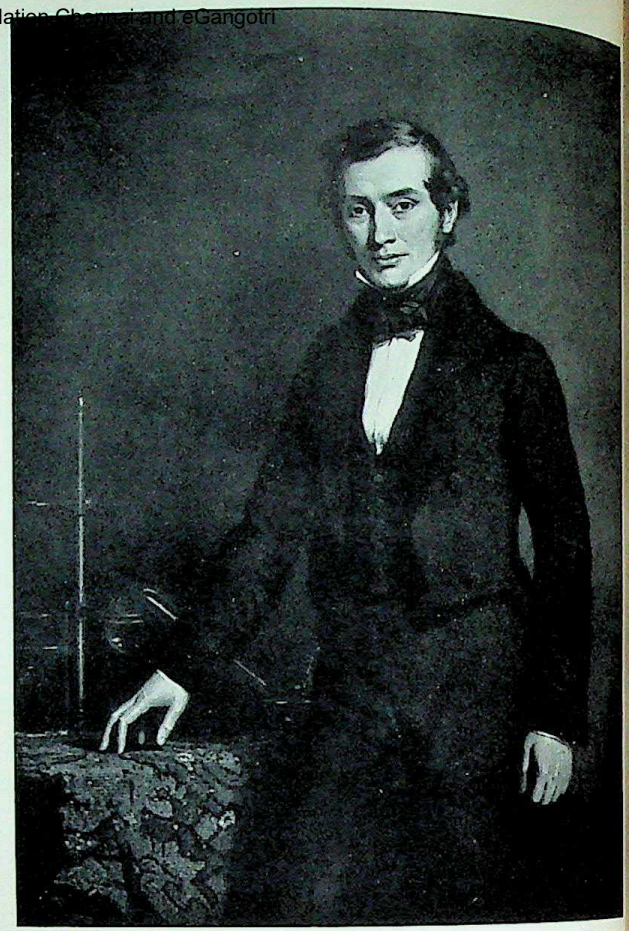

FIGURE 6 – *Thomas Graham, M.A., D.C.L., F.R.S. President* 1841–3, 1845–7. *(By courtesy of the Science Museum.)*

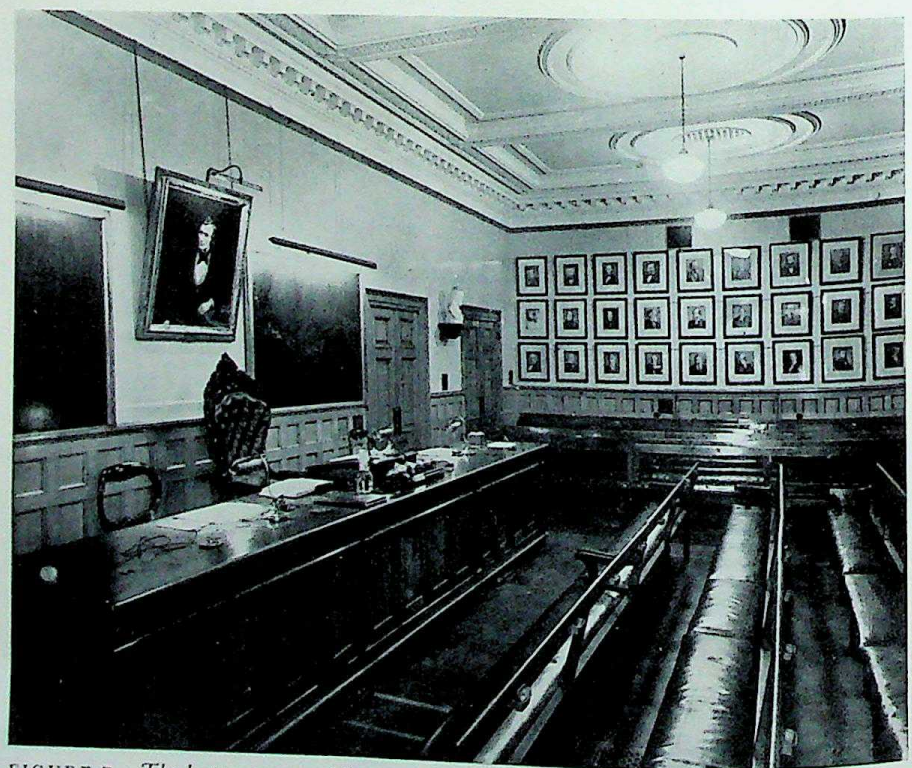

FIGURE 7 – *The lecture room with portrait of Thomas Graham above the President's chair.*

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poison gas. The cost of this memorial was defrayed from a privately subscribed fund of which part was used as a trust to establish the Harrison Memorial Prize of the value of £150. This is awarded every three years on the recommendation of a Committee composed of the Presidents of the Chemical Society, the Society of Chemical Industry, the Pharmaceutical Society, and the Royal Institute of Chemistry to the chemist, man or woman, not over thirty years of age, who shall have made the most meritorious contribution to chemical science during the previous five years. The first award was made in 1924 to Dr C. R. Harington, F.R.S.

The General Secretary's room was formerly the laboratory. On the ground floor are the rooms for the Honorary Officers and for Council Meetings. Apart from their use as part of the Library, these rooms, like the meeting-room, are used for office and editorial purposes whenever they can be spared. This very brief description hardly does justice to the home of The Chemical Society, which by the success of the work the Society has accomplished for the science has now become far too small.

Special lectures have been a feature of the proceedings of the Society since its inauguration. The Faraday Lectureship (1868), and the more recently endowed Hugo Müller, Pedler, and Liversidge Lectureships held by distinguished British and foreign chemists, provide valuable accounts of the most important developments in chemical science during the last eighty years.

In 1920 women were admitted to the Fellowship on the same terms as men. This change, somewhat heatedly contested, was followed by increasing the facilities to Fellows not resident in London. Regional representation of Fellows on the Council was instituted, alternate Annual Meetings are held outside London, and special and endowed lectures are delivered in provincial centres. Local representatives keep the Fellows in their respective districts informed of the Society's activities, and co-operate with other chemical organizations in the holding of joint meetings, discussions, and lectures.

From its foundation the Society has concerned itself with the publication not only of its own original contributions and lectures in its world-famous *Transactions* or *Journal*, but of abstracts of papers appearing in other journals. At first only British journals were abstracted, but in 1871 the abstracting service was extended, and from 1873 the abstracts were separated from what up to 1925 were styled *Transactions* and then became the *Journal*. In 1882 the Society of Chemical Industry began the publication of Abstracts of Applied Chemistry Papers. In 1923 the Bureau of Chemical Abstracts was started as a joint committee of The Chemical Society and the Society of Chemical Industry, concerned with the publication of *Abstracts A* (Pure Chemistry) and *Abstracts B* (Applied Chemistry). This first essay in co-operation between chemical societies has been an unqualified success. The pioneer work in the formation of the Bureau was carried out by Professor J. C. Philip, F.R.S., the first Chairman. The present Chairman is Dr L. H. Lampitt, President of the Society of Chemical Industry and *ex officio* member of the Council of the Chemical Society. It is now the Bureau of Abstracts, and is supported by The Chemical Society, the Society of Chemical Industry, the Physiological Society, the Biochemical Society, the Anatomical Society, and the Society for Experimental Biology. It is the largest and most important scientific abstracting organization in Britain.

The Society has published *Annual Reports on the Progress of Chemistry* since 1904, and can be justifiably proud of their success and high reputation among chemical publications. Publication of these Reports has been uninterrupted even during the two world wars, and important extension by the additional publication of review articles is now fully planned.

Co-operation between societies and organizations interested in the progress of the various branches of chemistry has been prominent, especially since the end of the 1914–18 war. In this movement The Chemical Society has always taken a prominent share. Even before the formation of the Bureau, The Chemical Society made its valuable library available to members of other societies. This co-operation of The Chemical Society with the Society of Chemical Industry and the Royal Institute of Chemistry has been greatly advanced by the establishment in 1935 of the Chemical Council. This consists of twenty members representing the three societies and the Association of British Chemical Manufacturers, which has helped The Chemical Society financially and in other ways for many years. Professor E. K. Rideal is the Chairman, and Mr F. P. Dunn, Hon. Treasurer of The Chemical Society since 1938, to whom The Chemical Society owes so much, has placed the Society further in his debt by acting as Vice-Chairman of the Chemical Council.

Each constituent of the Chemical Council

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retains its own individuality. It has established a Joint Library Committee with eight contributing organizations. Under the Chairmanship of Mr Dunn it has effected economies and increased efficiency in the production and distribution of the publications of The Chemical Society and the Society of Chemical Industry. Its system of joint membership of the three chartered organizations is in operation, and this has resulted in a marked increase in the Fellowship of The Chemical Society.

Since 1919 the establishment of Chemistry House, in which The Chemical Society will have an honoured place, has been the object of many efforts. The fulfilment of this project has now been assumed by the Chemical Council. If the Chemical Council is as successful in this as it has been and is in its other work—and there have already been generous benefactors—then The Chemical Society and its library will have in a reasonable time the accommodation they have so greatly needed and deserved for many years.

The Fellows of The Chemical Society can be rightly proud of the record of work accomplished by their Society for the extension of chemical knowledge during one hundred years, and of the Society's world-wide reputation. The future presents even greater opportunities than in the past for the work of the Society, and although they are conscious of many difficulties to be surmounted, its Fellows will by the quality of their investigations still further enhance its reputation.

PRESIDENTS OF THE CHEMICAL SOCIETY

	Years of Office
T. Graham	1841–1843, 1845–1847
A. Aikin	1843–1845
W. T. Brande	1847–1849
R. Phillips	1849–1851
C. G. B. Daubeny	1851–1853
P. J. Yorke	1853–1855
W. A. Miller	1855–1857, 1865–1867
L. Playfair	1857–1859
B. C. Brodie	1859–1861
A. W. von Hofmann	1861–1863
A. W. Williamson	1863–1865, 1869–1871
W. de la Rue	1867–1869, 1879–1880
E. Frankland	1871–1873
W. Odling	1873–1875
F. A. Abel	1875–1877
J. H. Gladstone	1877–1879
H. E. Roscoe	1880–1882
J. H. Gilbert	1882–1883
W. H. Perkin	1883–1885
H. Müller	1885–1887
W. Crookes	1887–1889
W. J. Russell	1889–1891
A. C. Brown	1891–1893
H. E. Armstrong	1893–1895
A. G. V. Harcourt	1895–1897
J. Dewar	1897–1899
E. Thorpe	1899–1901
J. E. Reynolds	1901–1903
W. A. Tilden	1903–1905
R. Meldola	1905–1907
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PAPER RESTRICTION

As a result of the shortage of power for industrial purposes in Great Britain, paper mills have been unable to maintain their normal production. A temporary reduction in the size of ENDEAVOUR will therefore have to be made, and each of the next two issues will consist of fewer pages than usual.

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Some physical instruments used in medicine

DAVID S. EVANS

Chemistry has always found manifold applications in medicine, and was indeed, in the days of iatrochemistry, merely the physician's Abigail. At the present time chemotherapy basks in the glory of such discoveries as penicillin, the sulphonamide drugs, and paludrine. The applications of physics to medicine have so far lagged behind, except in such cases as the use of X-rays and radioactivity in diagnosis and treatment. The many recent advances, however, leave no doubt that physicotherapy has as bright a future as chemotherapy.

The use of X-rays and radioactivity in diagnosis and treatment represents one of the most striking ways in which medicine has made use of physical discovery. So successful indeed, have researches of this character become that an important feature of the relation between medicine and physics tends to be obscured. In spite of the tremendous successes of physics, and in spite of the valuable contributions which physics has made to medicine in the field of X-rays and radium, and in nerve physiology, the general contribution of physics to medicine is far smaller than it might be, and there are many valuable links between the two sciences waiting to be forged.

This is a surprising conclusion in view of the earlier history of the relations between them. Before the differentiation of the sciences, the links were close. Gilbert, the author of a famous treatise on magnetism, was Queen Elizabeth's physician; Copernicus was, at least ostensibly, a physician as well as a priest and an astronomer. Even much later, Thomas Young, known to physicists for his work on light waves, was a physician by training. von Helmholtz had his first education in medicine, and the early conclusions on the conservation of energy were based on physiological experiments.

It seems as if the division between the two sciences was a temporary one only, and now the gap is being closed. As medical men require for diagnosis a more and more detailed investigation of their patients it is inevitable that physical problems of diagnosis should come to occupy a larger place in their thoughts. As medicine arms itself with more and more complex instruments for diagnosis and treatment, so it meets more and more frequently physical problems of design beyond the capacity of the medical specialist to solve. Co-operation between the two sciences was greatly encouraged by the late war, when the medical profession found itself faced with problems of casualties and disease of an entirely new order of magnitude, and in the solution of some of them sought the aid of the physicist.

It is not unfruitful to begin the discussion with a consideration of the differences in viewpoint between the physicist and the medical man. On the one hand, the physicist is accustomed to the study of situations involving rather few variables: his experimental conditions are fairly accurately reproducible, and his interpretation of results has a mathematical exactness and niceness. If he is a mathematician as well, he will notice in himself a tendency to believe that he has said all that is worth saying about a problem once he has cast it into mathematical terms, and may even exhibit a dogged determination to defend his mathematical deductions as enshrining the whole truth.

The medical man, on the other hand, shares with his colleagues in the biological sciences all the difficulties consequent upon large individual variations in his material: his primary aim is to diagnose and cure, and here he is faced with a situation embodying an enormous number of factors which defy numerical definition. He tends, and rightly so, to rely on a general assessment of a complex picture in which many of the features have indefinite and almost imponderable qualities which can be judged only by experience.

This attitude indicates the medical problems which can be profitably studied by the physicist. He must, throughout, be guided by his medical colleagues and must not attempt to dominate the situation. The services which he can render are, firstly, to assist diagnosis by providing means for more accurate assessment of physical symptoms, so delineating more firmly part of the general clinical picture. Secondly, he can devote his

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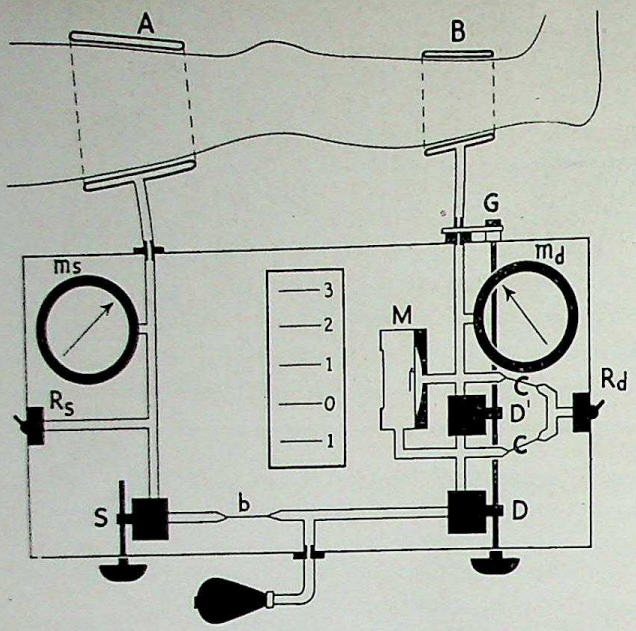

FIGURE 1 – *Circuit of blood-pressure indicator.*
(*Reproduced from the* British Journal of Anaesthesia.)

M = *Membrane manometer.*
m_s, m_d = *Aneroid manometer.*
D' = *By-pass tap.*
D = *Inflation tap, linked to* D'.
C–C = *Capillary.*
R_d, R_s = *Release valves.*
S = *Systolic circuit tap.*
b = *Capillary.*
G = *Safety gate.*

attention to methods of physical clinical treatment and, by physical investigation, render them more precise and more readily controllable.

A third feature of the relationship between the two sciences must be mentioned. As a result of his attempts to aid diagnosis the physicist may provide the medical man with some new instrument: this must be not only reliable in its readings but very robust and easy to operate. A device which is so delicate that it cannot withstand the hazards of use in general medical work, which often needs servicing, or which is so difficult to operate that the practitioner would be better occupied in giving his attention directly to the patient, will soon be discarded. Better by far to produce a less accurate device which can be operated by the turn of a switch and which will survive—for example in military use—a fall from a lorry [1].

Two examples of the work done by the writer in collaboration with Dr K. Mendelssohn will illustrate the practical application of these principles. The first problem was to devise an instrument for the measurement of blood-pressure, preferably by a continuous indication.

The medical background of this problem is as follows. A fall in blood-pressure is one of the earliest signs of the onset of shock in patients in the operating theatre. In casualties a low blood-pressure is a possible indication of a state of shock, although the difficulty here is that the normal blood-pressure even of healthy persons shows a wide variation. As an aid to the anaesthetist, however, who is responsible for keeping the patient in the operating theatre in good shape, the completest possible knowledge of the blood-pressure variations is of the first importance.

The pressure in an artery is not constant, but varies cyclically with the action of the heart. The standard medical method of specifying the blood-pressure is by the maximum and minimum pressures attained during each cycle, these being known as systolic and diastolic pressure respectively. The difference between the two is called the pulse pressure, and it is possible that this quantity represents the best index of the circulatory state of the patient.

The ordinary method of determining systolic and diastolic pressures is by the aid of a rubber cuff which is bound round the arm and can be inflated to any desired pressure, the pressure being read on a mercury or aneroid manometer. A stethoscope is applied to the brachial artery distal to the cuff, and the sounds heard in this at different cuff pressures form the basis of the estimation of the required pressures. Roughly the procedure is as follows. It is assumed that the pressure in the cuff is transmitted through the tissue to the artery. If, therefore, the cuff pressure be greater than systolic, the artery beneath the cuff will be occluded, no blood will flow past the obstruction, and no pulse sounds will be heard in the stethoscope. If the cuff pressure is lowered to a value intermediate

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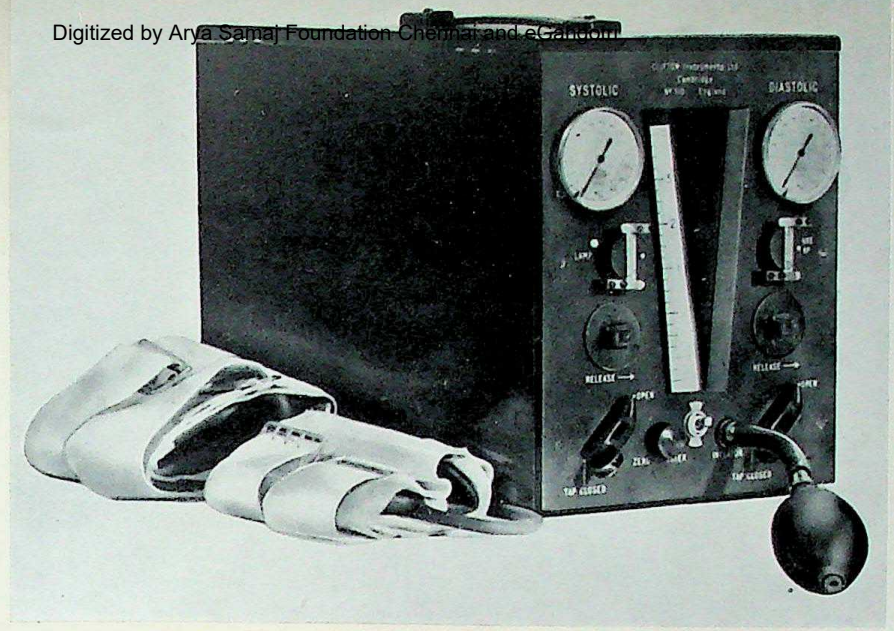

FIGURE 2 – *Blood-pressure indicator. The pulsations are shown by the movement of a light-spot on the central scale.*

FIGURE 3 – *Radiation flux-meter. The upper receiver disk, supported on a copper block, is visible. The lower disk faces the water jacket forming the base of the instrument. Water tubes and electrical leads pass through the handle.*

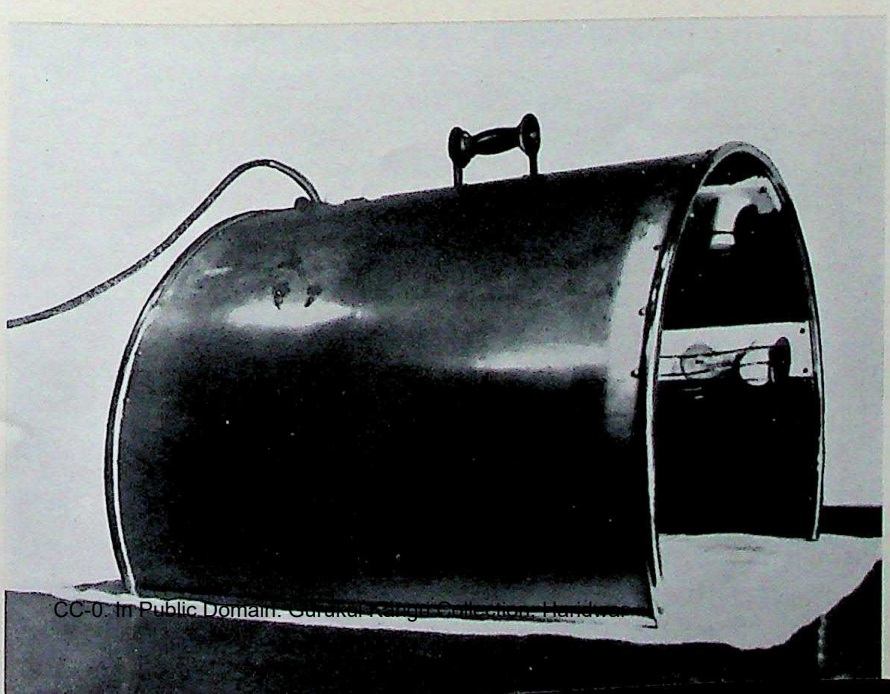

FIGURE 4 – *Radiant heat cradle. (For experimental purposes the inside surface of the metal horseshoe has been blackened.)*

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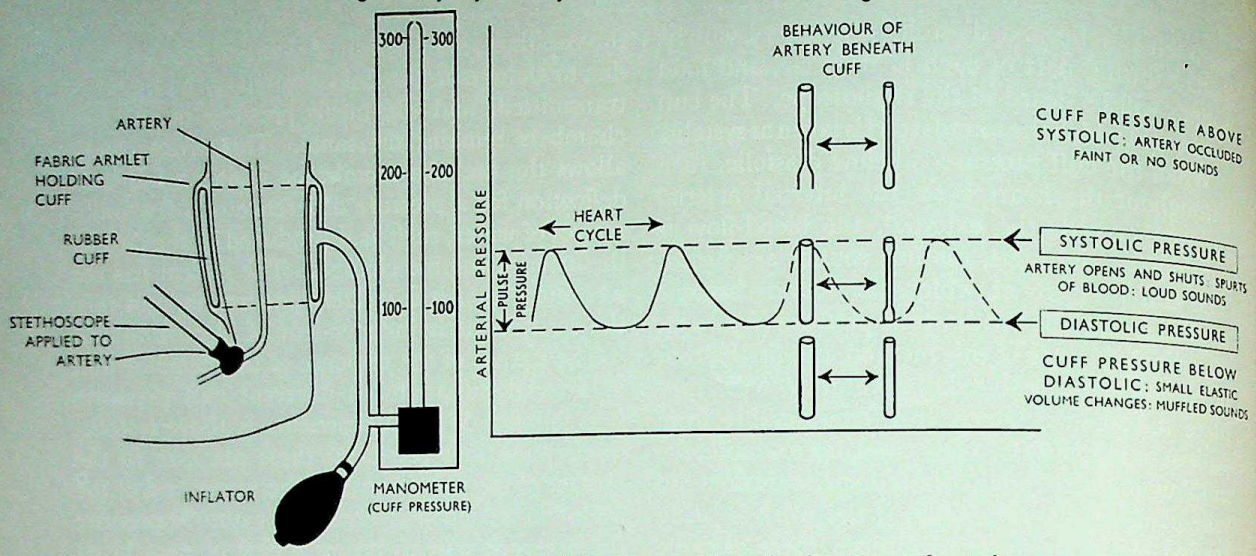

FIGURE 5 – *Schematic representation of blood-pressure determination by use of a stethoscope.*

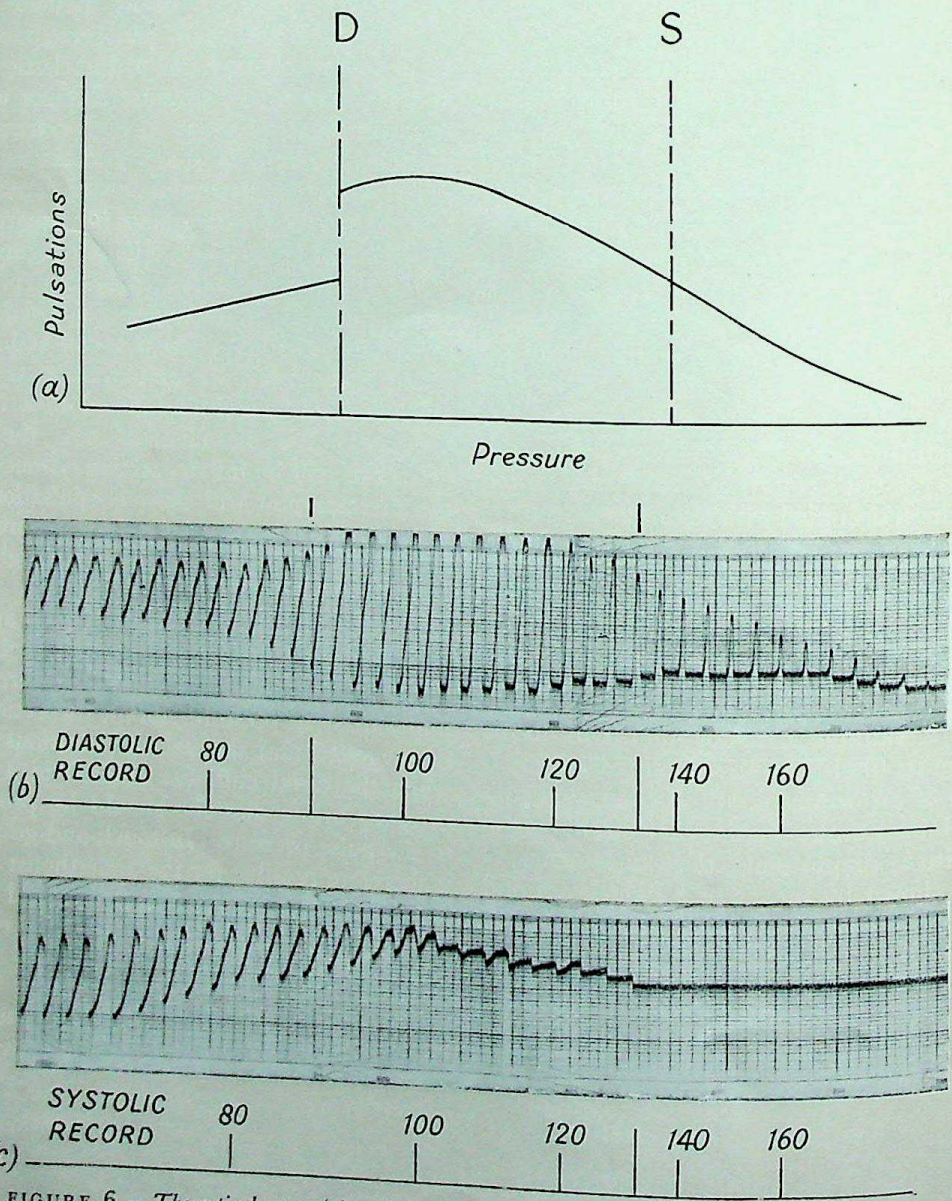

FIGURE 6 – *Theoretical curve (a) and recorded pulsations (b) and (c), in detector circuit of the blood-pressure indicator.* (*Reproduced from the* British Journal of Anaesthesia.)

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between systolic and diastolic, the artery will be patent during part of each heart cycle, and loud sounds will be heard in the stethoscope. The cuff pressure at which the sounds start is taken as systolic.

When the cuff pressure is below diastolic, then throughout the heart cycle the internal arterial pressure exceeds the external, the blood-flow is continuous, and faint, muffled sounds are heard. The cuff pressure at which the sounds become muffled is taken as the diastolic pressure (figure 5). The disadvantages of this method are, firstly, that it requires considerable skill accurately to discriminate the sounds, which vary considerably from patient to patient. In a few cases, for example, the muffling of the sounds at diastolic pressure does not take place at all. Secondly, if the work is being carried out under war conditions there may be sufficient noise to drown the sounds altogether. In the operating theatre blood-pressure determinations are carried out by the anaesthetist, using a tambour strapped to the arm of the patient, and this is usually completely inaccessible under sterile drapes. The manipulations of the surgeon may prevent the anaesthetist from securing an uninterrupted hearing of the sounds, or may even displace the tambour, which can never be held in place with the same security as a cuff surrounding the limb, and the anaesthetist may then be left with no means at all of making blood-pressure determinations. In addition, the auditory method is discontinuous, and each determination requires, for the moment, the full attention of the anaesthetist. At the same time, the touch-and-go periods when the anaesthetist has most need of a guide to his patient's condition are precisely those when he is most occupied with restorative measures such as blood-transfusion. Finally, the auditory method can be used only on the arms, and, even if these are not involved in the operation, they are often needed for blood-transfusion, continuous intravenous anaesthetics, and so on.

In order to replace the auditory by a visual indication a suitable detector unit had to be devised. In its final form this consisted (figure 1, right side) of an ordinary cuff *B* connected to a differential membrane manometer *M* having a very sensitive diaphragm, the movements of which are shown by means of a light-beam and scale. The cuff is connected directly to one chamber of the manometer; the two chambers are connected by a capillary *C*. The effect of this arrangement is that rapid pressure-changes are conducted into the first chamber and produce movements of the membrane but are baffled by the capillary; slow pressure changes such as those due to changes in the fluid content of the limb are transmitted, and the mean pressure in the two chambers remains the same. This arrangement allows the use of a membrane giving a full-scale deflection for a pressure difference of a few millimetres of water, such as is produced in the cuff by the arterial volume changes. The system has the advantage that it is entirely pneumatic, and thus the instrument is independent of electric mains.

The nature of the response of this detector unit to arterial pulsations at different cuff pressures is as follows. If the cuff pressure is above systolic, small pulsations are seen; these are due to the impact of the pulse wave on the upper end of the occluded section of artery. Below systolic pressure the artery is patent during a part of each heart cycle, and large pulsations are seen, corresponding to the large volume change from complete occlusion to complete patency. Below diastolic pressure the pulsations are small, and correspond to the small volume changes due to the elastic response of the artery to the pressure changes within it. A closer analysis shows that the transition at diastolic pressure is sharp and forms a good criterion for the determination of diastolic pressure: at systolic pressure there is no sharp change which might be used as a criterion (figure 6).

For the determination of systolic pressure a second cuff *A* is therefore employed, placed proximal to the first. The first cuff and its membrane manometer are employed as a detector unit, and this circuit is inflated to a moderate pressure below diastolic. If now the second, proximal, cuff be inflated above systolic pressure the detector unit will show no pulsations: these will start suddenly when the pressure in the proximal cuff is allowed to fall through systolic pressure (figure 6, systolic record).

A third use of the instrument, which appears to be new, is the possibility of using the distal cuff alone for the indication of pulse pressure (systolic minus diastolic pressure), for the theoretical analysis suggested that the size of pulsations observed when the distal cuff was inflated to a constant pressure below diastolic should be proportional to the pulse pressure. In touch-and-go periods it is therefore possible for the anaesthetist to set the machine to record pulse pressures and to follow them visually while he applies his restorative measures.

The apparatus in its final form is shown in figure 2. The design involved a number of mechanical problems, such as the provision of a

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type of totally enclosed, leak-proof tap, and automatic safety devices for the protection of the membrane. The machine has proved robust and has shown itself capable of a number of uses not originally envisaged. For example, it can be used for blood-pressure measurement in the leg, which is not possible by the auditory method. It is applicable to the detection of circulatory abnormalities and to the investigation of rapid physiological changes in the circulation under various experimental conditions. Other developments included a model adapted for photographic recording, and, for the Industrial Health Research Board, a model for recording blood-pressure in the temporal artery while all the limbs were in use [2], [3], [4].

The second problem, drawn from physiotherapy—a particularly fruitful field for physical investigation— concerns the application of infra-red radiation for medical purposes. It is a curious fact that, in sharp contrast to X-rays and gamma rays, the field of medical application of infra-red rays has not been very extensively investigated. Signal exceptions are provided by the researches of such workers as Mayneord and his collaborators [5], and the Medical Research Council has recently established a Committee on Non-ionizing Radiation, which should quickly remedy remaining deficiencies. The reason for this state of affairs is probably to be sought in the differences in physiological action between short-wave and long-wave radiations. In the case of the short waves the most obvious effects are due to specific quantum changes produced in the tissues: these are proportional to the intensity of radiation and often take some time to become fully apparent, so that careful control of dosage is essential. Infra-red radiation, on the other hand, is all in wavelengths so great that the quanta are insufficiently energetic to produce specific reactions, and the only effect appears to be a heating of the tissues, which is noticed almost at once by the patient and can be controlled by the physician. On the other hand, there is a vast difference in scale of the energy used in treatment. In a single treatment, infra-red radiation of a total energy of as much as 20,000 calories may be administered, and doses of this magnitude require careful control, since they approach those capable of causing severe burns, and even of disturbing the general heat-elimination processes of the body.

The specific problem which introduced us to this field arose out of burns caused by a piece of medical apparatus known as a radiant heat or anti-shock cradle (figure 4), which consists simply of a horseshoe-shaped metal sheet fitted on its inner surface with a number of electric light bulbs. This device is placed over the patient and switched on, the object being to keep him warm and to delay the onset of shock. The actual conditions of treatment vary a good deal. Usually the cradle is draped with blankets; sometimes the patient is also wrapped in blankets; sometimes he is treated naked.

The first instruments used in the investigations consisted of various forms of disk receiver forming one junction of a thermocouple, and it soon became clear that a serious time-effect was involved [6]. Evidently the original intention of the metal horseshoe had been to serve as a reflector of radiation, but its real function turned out to be quite different. It actually absorbed a considerable proportion of the radiation, and after an hour or so acquired a fairly high temperature and began to act as a secondary radiator, the area of which was so large that it eventually contributed twice as much as the lamps themselves to the radiation received by the patient. The danger was, therefore, that even if some measuring device were used at the beginning of treatment to determine the dose received by the patient, this precaution would be invalidated by the steady increase in the radiation received. A second point is that this secondary radiation is all in wavelengths so great that it would be absorbed by glass, so that if the treatment were conducted by following the readings of an ordinary glass-enclosed thermocouple, the increase in radiation would not be detected.

It therefore became necessary to devise an instrument for the measurement of radiation flux in all wavelengths, and to recommend that the basis of treatment should always be direct measurement with such an instrument of the actual flux received on the patient's skin throughout the treatment [7]. This recommendation is in contrast to that for X-rays, where the physician relies on calculation of the dosage [8]. It is indeed possible to calculate the infra-red dosage received in any given set of circumstances, but such calculations are too involved to be a feasible method for the ordinary physician.

The instrument devised [9], [10] consists of a pair of disks, carrying thermojunctions on their reverse faces, mounted on opposite sides of a small copper block (figure 3). One disk receives the radiation flux to be measured, while the other is opposed to a water jacket with a blackened surface,

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through which water at room temperature is flowing. The construction was aimed at securing a direct-reading instrument responsive to the whole range of infra-red radiation likely to be encountered, accurate to within about 5 per cent., and independent, as far as possible, of the air temperature in which it had to operate. The assessment of the physical factors involved, which were concerned with the transfer of energy by radiation and conduction under conditions removed from thermodynamic equilibrium, proved surprisingly tricky. The final instrument, which shows a linear response to radiation flux, seems to approximate to the best compromise between a number of conflicting physical requirements, and fulfils the conditions imposed reasonably satisfactorily. It also satisfies the medical requirements of robustness, ease of reading, and cheapness of construction. It should therefore now become possible to develop a satisfactory quantitative control of infra-red treatment leading to a better understanding of the effects of this type of therapy. The most important deficiency at present is that so far it has not proved possible to obtain independent measures of the radiation in various spectral ranges, but this is not a serious defect, since, as far as is now known, there is little difference in therapeutic effect between different infra-red wavelengths except for some difference in depth of tissue penetration.

It may be of interest to recall some of the other types of problem dealt with in this general programme. They ranged from the development of methods for the measurement of pressures in small anatomical cavities [11], such as the middle ear; the manufacture and use of devices for measuring subcutaneous [12] and skin-temperature [7], [13], and the construction of a device for the accurate measurement of the volume of a limb; to theoretical analyses of the processes involved in the transmission of light through tissues [14].

It should be pointed out that this account is of a partial nature and is concerned mainly with the work with which the writer has been concerned, but it would be unfair to omit to note some of the more important work which has been carried out by other workers in the field. An excellent summary of work done in Great Britain is provided by the *British Medical Bulletin*, **3**, 6, 1945, containing a general introduction by Professor Mayneord, whose work on infra-red radiation has already been mentioned; an article on biophysical factors in drug action by Dr H. Hurst; a survey of the application of electronics to medicine by Dr G. E. Donovan; and a discussion of the physical factors involved in the causation of brain injuries by Dr A. H. S. Holbourn. The wide field of the applications of electronics to medicine, the recent development of the use of artificially radioactive substances in physiological investigations, and the use of increasingly high-voltage X-rays and of neutrons in medical treatment [15], are among the most striking applications of physics to medicine. They have already attracted a considerable number of workers, particularly in the United States, but it has been our own experience, which is borne out, for example, by Dr Holbourn's fruitful application of the classical notions of elasticity and hydrodynamics to the study of brain injuries [16], [17], [18], that there remains a very large field in which less spectacular physics may aid medicine.

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Aerial photography

C. H. WADDINGTON

Cartography is a science essential in both war and peace, though historically the main impulse to the making of maps has been military: the Ordnance Survey was originally a branch of the Royal Artillery, and Napoleon's campaigns led to the first detailed maps of France. The war of 1939–45 stimulated the effective development of cartography by means of aerial photographs. Professor Waddington discusses the possibilities and limitations of the method, and shows the importance of aerial photography for peaceful purposes.

It is well known that during the war aerial photography was one of the most important means of finding out what was going on in enemy countries. In the early days, when Britain was expecting an invasion, it was vital to know if, and where, the Germans were collecting barges and landing craft: it was a task for the Royal Air Force, with its cameras, to keep a continual watch on the Continental ports. Later it had to provide the information by which we could judge the success of our bombing offensive, and the effectiveness of various types of attack. Through the newspapers we became familiar with aerial photographs of acres of devastation in German cities. But these were only the most spectacular, and the most fully publicized, of the achievements of aerial photography. In a more general sense we can say that this technique has become the modern equivalent of cartographic surveying. Generals have always demanded the fullest possible information about the country in which they are to fight, and this demand has been one of the crucial arguments which have persuaded countries to undertake the laborious work of preparing accurate maps. The connection between map-making and military affairs is reflected in the name of the official agency for mapping Great Britain—the Ordnance Survey—which was originally a branch of the Artillery. Similarly, the official maps of France are those originally produced by Napoleon for military purposes.

A century or more ago the military demand for information about potential battlefields was generally met by a survey, conducted on the ground, which recorded only the physical shape of the solid earth and the main features such as roads and towns. Nowadays aerial photography provides not only an accurate map of the same features but also a very detailed account of the nature of the land surface. This may often be of fundamental military importance: a commander will want to know not merely that there is an open area between two roads, represented by a blank space on the map, but much else besides; is it hard ground suitable for tanks, or swampy, or covered in bushes? All this can easily be read from the aerial photographs, and expert examination can extract an extraordinary wealth of information from them. Much of this is, of course, of even more importance for peacetime pursuits than for warlike ones. Normal cartographic maps, prepared originally for soldiers, are recognized as essential tools for all kinds of civil enterprises, not only for legal battles about boundaries, but for every major undertaking of engineering or construction. Aerial photographs, because of the more complete information they may contain, will become the new form of map essential for undertakings of agricultural development, forestry, control of erosion, and so on. The military organization built up for interpreting aerial photographs during the late war is likely to be gradually absorbed, in some form or other, into the service of civilian affairs, just as the Ordnance Survey was in an earlier period.

This does not necessarily mean that surveying on the ground has gone out of date. It will probably remain for some time a better method of obtaining extreme accuracy than surveying from the air. If we are concerned only to produce a physiographic map of the normal kind, the advantages of the air are not in greater accuracy but in rapidity. It is, for instance, obviously very easy to use aerial photography to make frequent revisions of an already existing map, so as to keep it up to date. There are even greater advantages in undeveloped countries where travel is difficult. Aerial photography can be used to fill up the spaces in a grid of points whose position has been fixed by triangulation on the ground, but it will probably soon be possible to dispense with all ground control over very wide areas. Experiments

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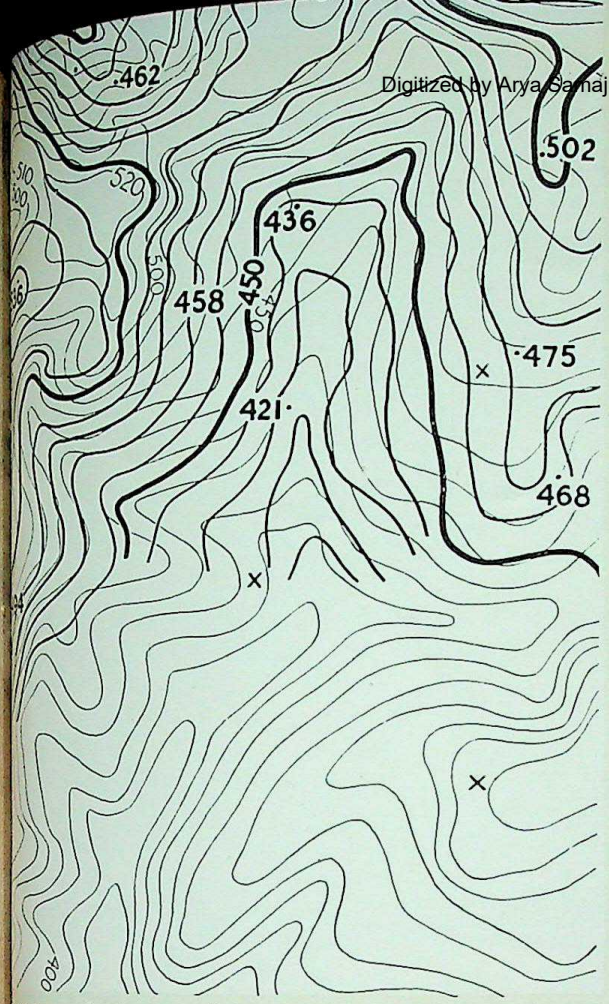

URE 1 – *Comparison of contours based on the use of ar fixes (heavy lines) to locate the photographing aircraft in ht, with the contours recorded by accurate ground survey. ntours at 100 ft. intervals.) The material was worked out m one of the first experimental flights, the nearest ground tion of the radar system being 85 miles away.*

FIGURE 2 – *Comparison of roads mapped in the same experimental radar-controlled flight with those recorded by ground survey. (The roads mapped by radar are printed in black.)*

FIGURE 3 (*below*) – *Venice, showing the Piazza S. Marco.*

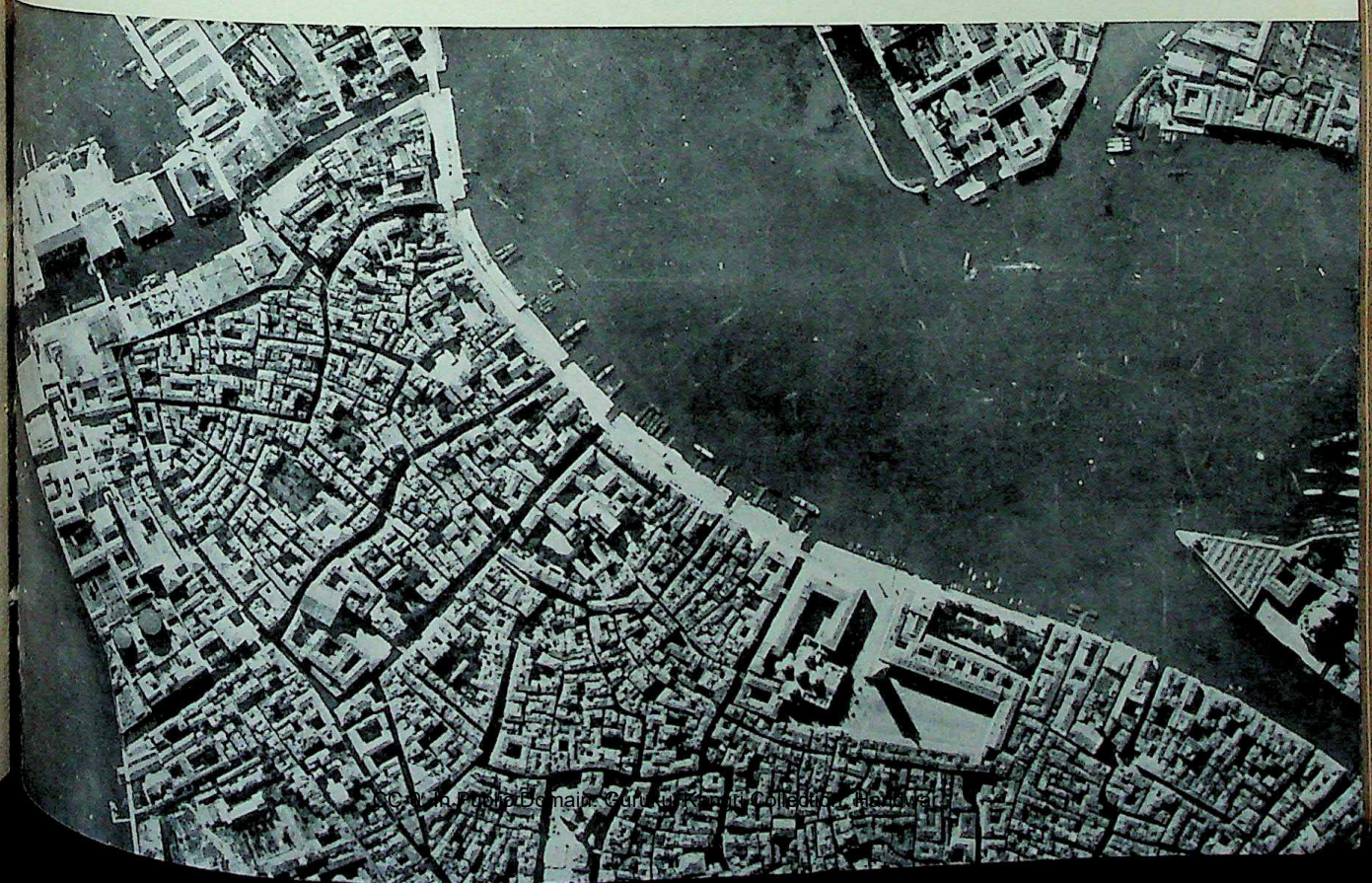

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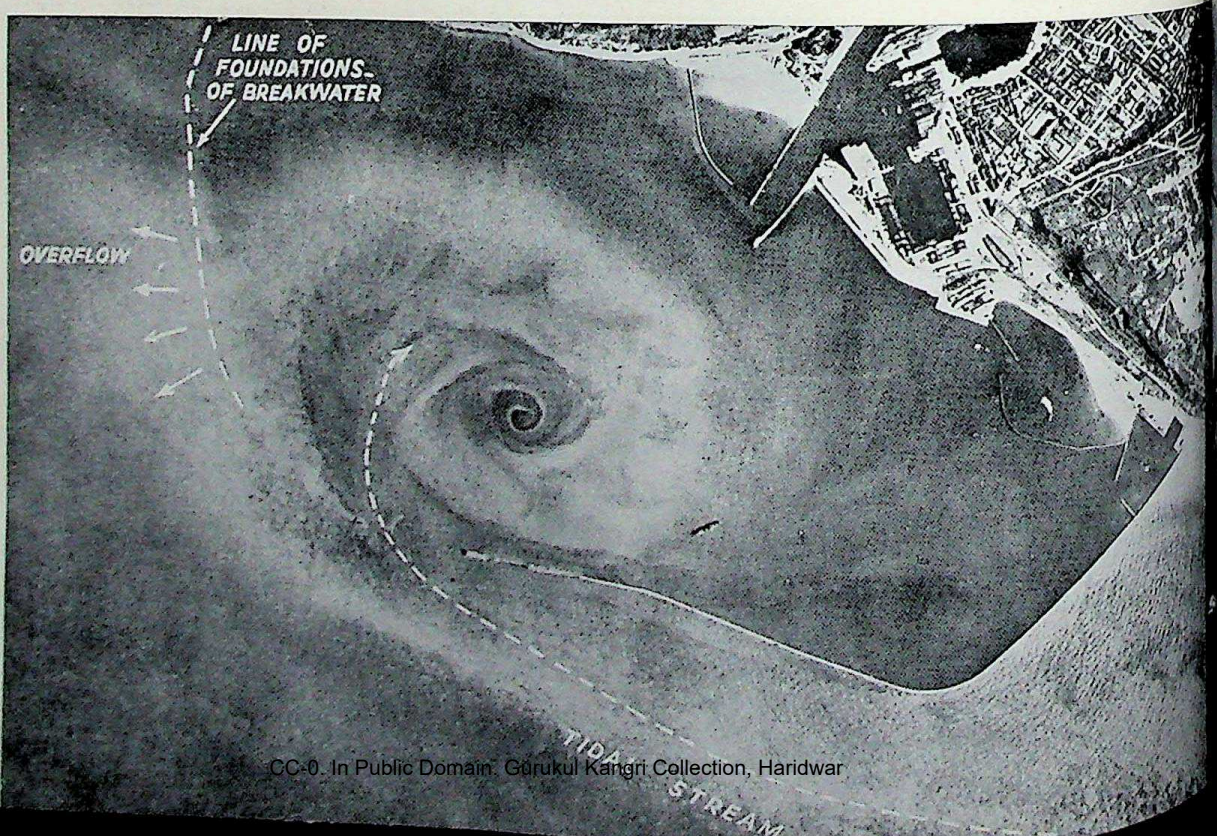
FIGURE 4*a* – *Boulogne harbour at low tide, with the dredged channels showing up clearly.*

FIGURE 4*b* – *Boulogne harbour during the maximum spring tides, showing how a whirlpool is formed in the mouth of the harbour by silt-laden water.*



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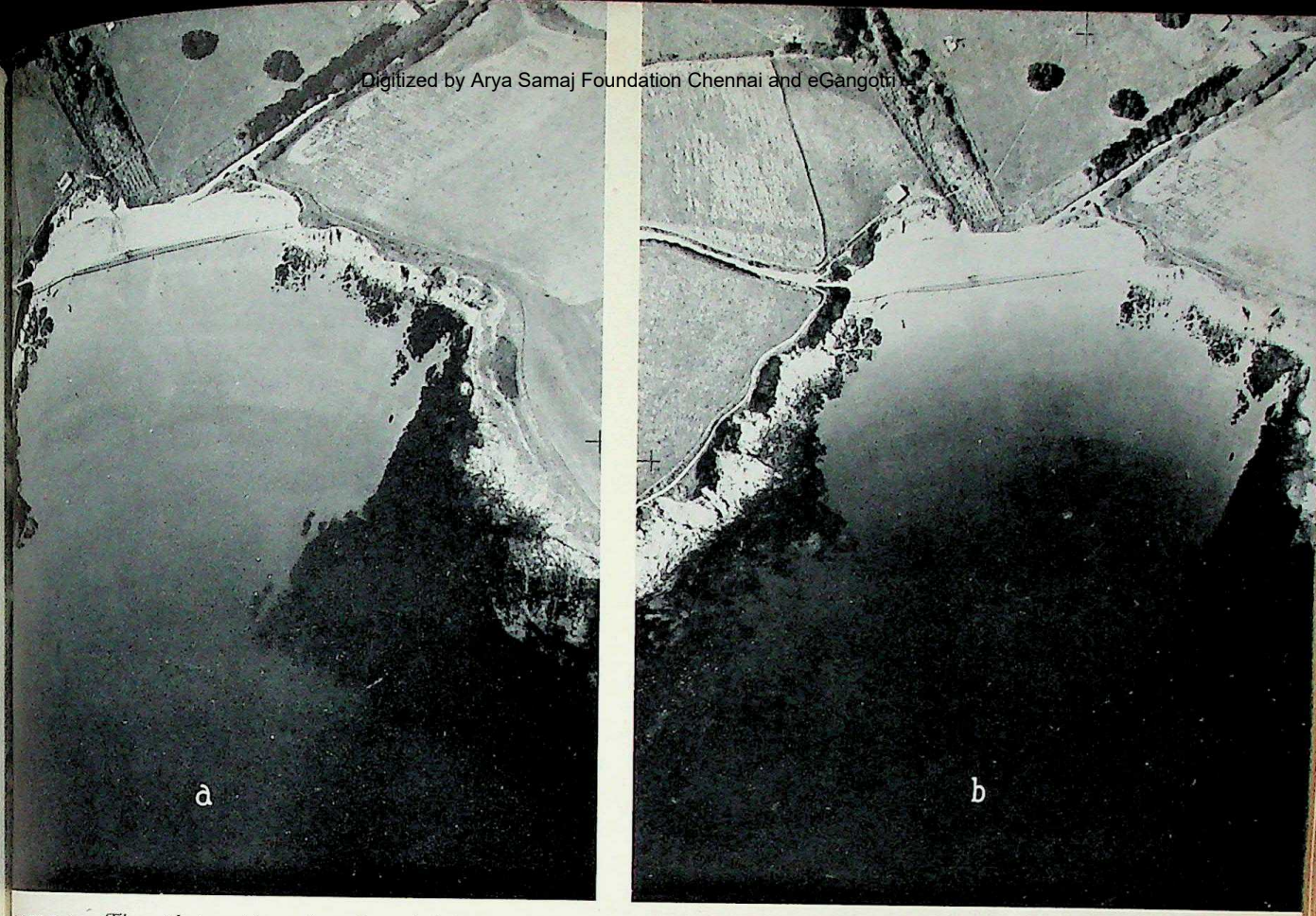
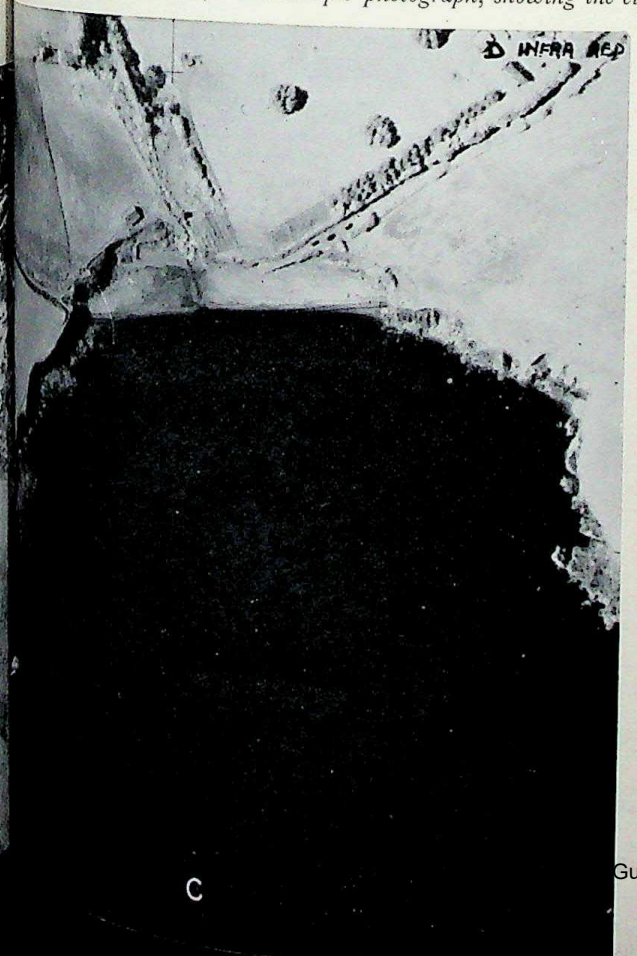
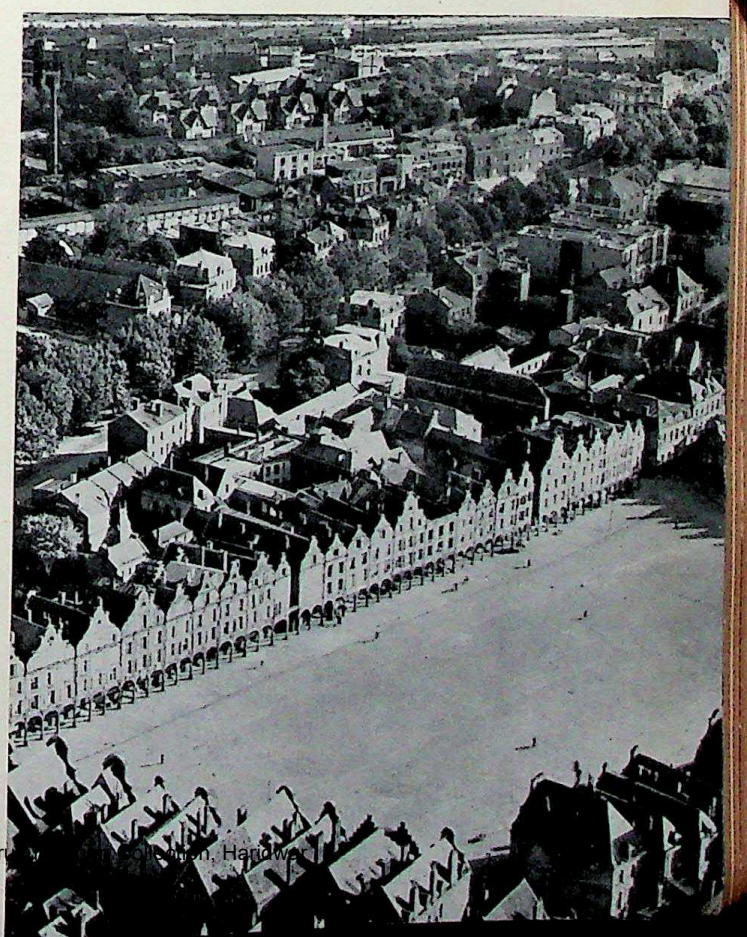


FIGURE 5 – *Three photographs, taken through (a) green, (b) red, and (c) infra-red filters, of a sandy cove in Cornwall. Notice the deeper gradation of tone in the sea on the red photograph in comparison with the green one. Notice also the position of the water-line, which is sharply revealed by the infra-red.*

FIGURE 6 (*below, right*) – *An oblique photograph, showing the eighteenth-century Dutch gabled houses in the Grande Place at Arras.*





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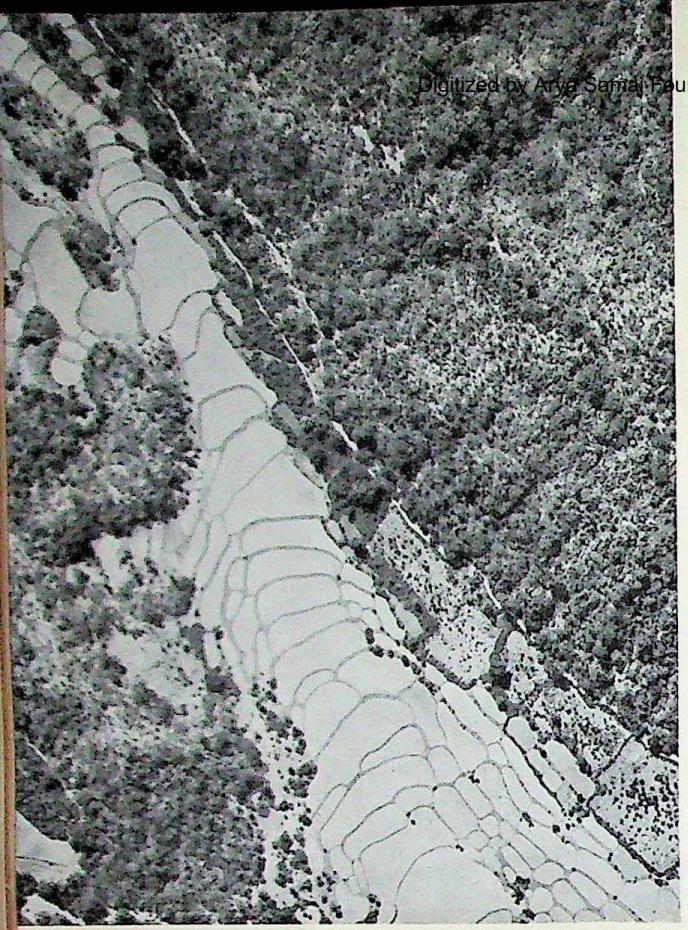

FIGURE 7 – *A tongue of terraced paddy fields extending up a small valley.*

FIGURE 8 – *A village with scrub on one side, and, on the other, fields with ground-nuts and similar crops.*

FIGURE 9 – *Most of the larger fields shown here contain bush crops such as tobacco, but there are also some small rice fields in the low-lying parts.*

FIGURE 10 – *A coco-nut plantation, with deciduous forest behind it. The beach is a coral reef.*

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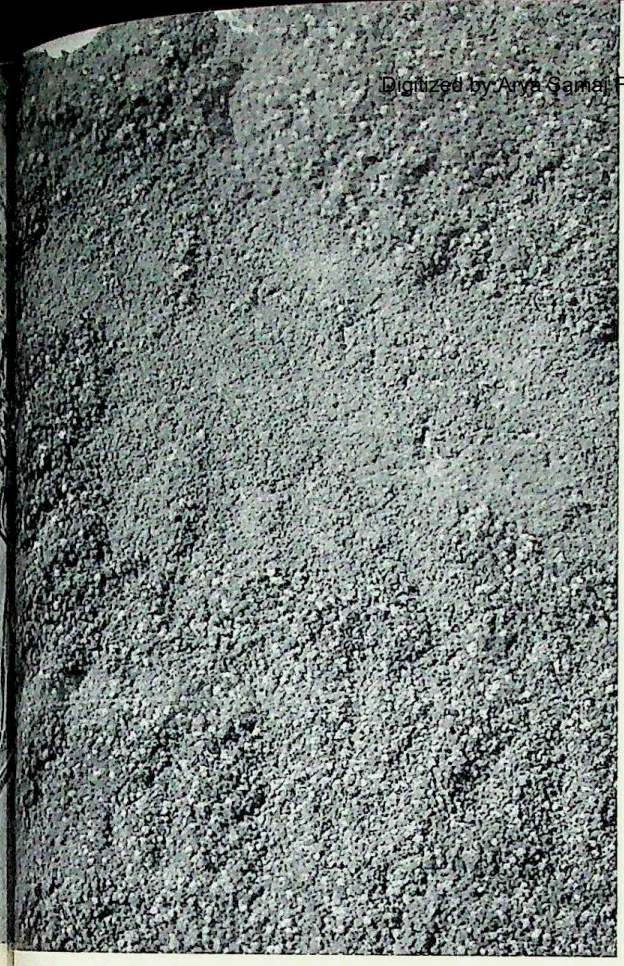

URE 11 – *In this difficult country, two types of jungle be easily distinguished.*

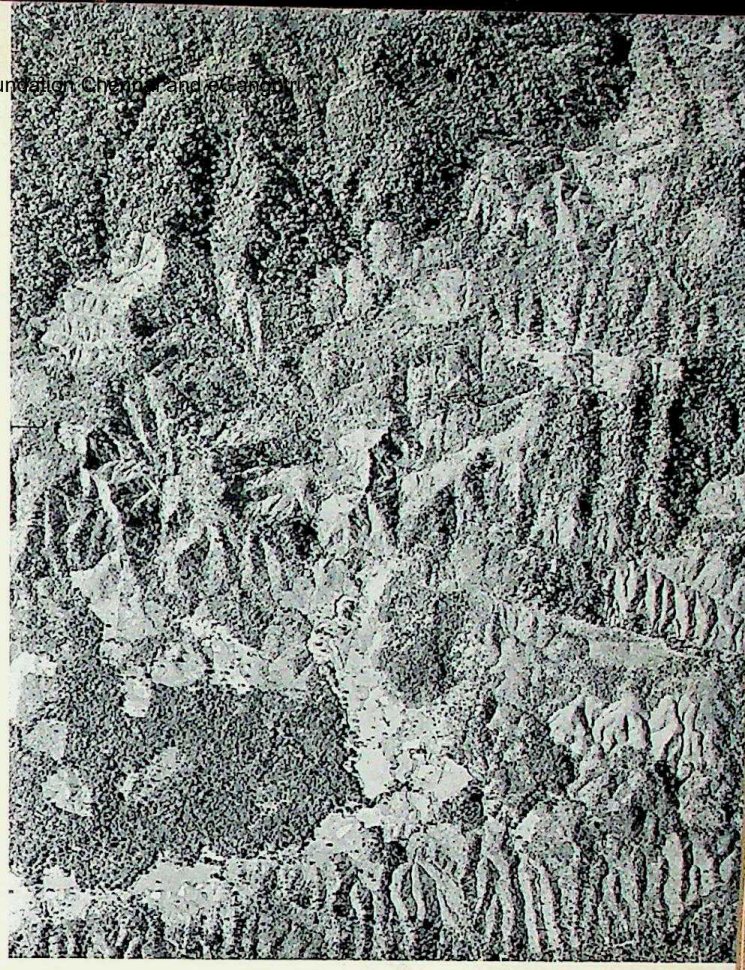

FIGURE 12 – *The hills at the top of the photograph are covered with relatively untouched jungle, but over most of the area the hillsides have been felled and burnt, the land used for a few crops, and then allowed to revert again to forest.*

URE 13 – *A cultivated plain, beginning to suffer badly erosion along the valleys.*

FIGURE 14 – *Houses set amid coco-nut groves, photographed with a moving-film camera* (*page 84*).

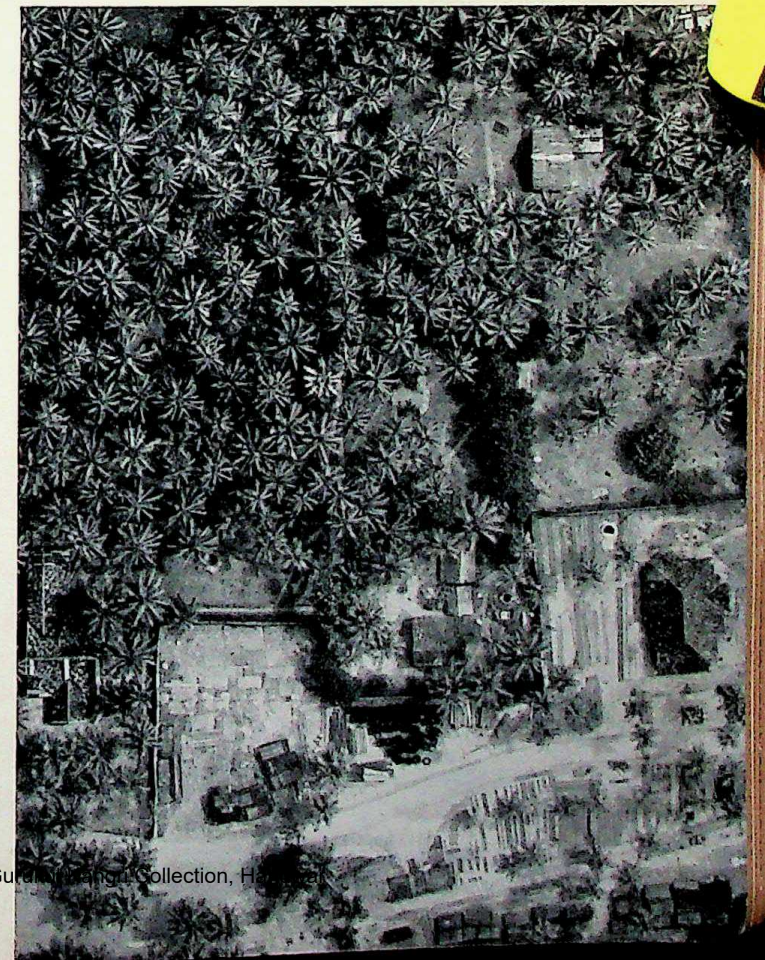

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FIGURE 15.—*Den Helder, a Dutch town which is nearly enclosed within its ancient fortifications.*

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are now proceeding on the use for survey purposes of some of the radar devices which were developed to aid the navigation of a bomber to its target at night. By means of these instruments one can determine the position of the aircraft, relative to the two or more ground stations transmitting the signals, at the instant of photography. Very accurate maps can then be made up to distances—at present—of a few hundred miles. An example, from one of the first experimental flights, is illustrated in figures 1 and 2. This technique is very rapidly advancing, and it is likely that it will soon be able to play an important role in surveying many comparatively undeveloped regions of the world.

One rather specialized branch of surveying work in which the cheapness and speed of air photography show to unexpected advantage is the investigation of the under-water topography near the shore. By choosing favourable conditions of wind, sun altitude, and other factors, it is possible to take aerial photographs which register details of the bed of the sea down to twenty or thirty feet, which is deep enough for most practical purposes of coastal navigation. Figure 4 shows how one can get an overall picture both of the success of harbour dredging and of the currents which bring in the silt. These photographs were taken in routine reconnaissance. Much more exact information can be obtained by special techniques. Perhaps the most generally useful of the latter is simultaneous photography through red and green filters. Through a green filter the bottom can be seen to a greater depth than through a red one; in a green-filter photograph the graduation in tone from the shore to the black of the deep sea will therefore be more gradual than in a red photograph (figure 5). By expert comparison of the two photographs depths can be determined with considerable accuracy, the maximum range depending on the nature of the bottom, the muddiness of the water, and other factors. This type of interpretation can be reliably done only by experts, but their results compare very favourably with those obtained directly by the laborious process of taking soundings (figure 16).

It is when the aerial photograph is considered as a supplement to a map, giving information which is normally not plotted by cartographers, that its greatest advantages appear. For town planning, for instance, a set of air photographs will not only give an accurate picture of all the recent additions to the town and make it possible to work out the heights of buildings as well as their plan position, but will show the character of the town in a vivid and realistic way which is quite impossible on a map. The town planner can get his photographs at the scale which is most appropriate for his particular interests (figures 3, 6, and 15). He may want to study a whole region, and the relation between town, agricultural land, forests, parks, hills, and so on; or he may be interested in more detailed matters. In any case the air photograph will present the material in a way which, unlike the normal map, does not omit the aesthetic qualities on which good town planning so largely depends.

Another most important use of aerial photography in peacetime will be for the preparation of land-utilization maps. One can, of course, very easily distinguish the main categories of land—arable, grassland, woods, parks, and so on; and land-utilization maps can be made which are not out of date before the survey has been completed, an achievement which is scarcely possible when such maps are made from ground studies unless a prohibitively large staff is employed. From aerial photographs, moreover, one could go into considerably greater detail than is worth attempting in ground maps which can be revised only at long intervals. Many of the most important crops can be distinguished in photographs on quite a small scale. More research is still needed on this type of interpretation; many of the appearances presented by crops at different stages of their growth are somewhat unexpected and deceptive to the layman, but it is clear that we can already get much more up-to-date information about the purposes for which land is used than has been available before.

This may be of particular importance in regions which are comparatively undeveloped, where agricultural statistics are usually even more incomplete than in the longer-settled countries. Figures 7–11 show some typical examples of various agricultural crops growing in Burma: clearly from such photographs one could make fairly exact estimates of the acreage used for different purposes. Moreover, the administrator can keep a continual check on the fleeting cultivations which some semi-nomadic peoples set up in the jungles (figure 12), and can discover when the burning of the cover of trees is going too far, or erosion is becoming dangerous (figure 13). A valuable indication of forest resources can also be obtained: the main ecological types of forest can be mapped, and, if necessary, the supplies of

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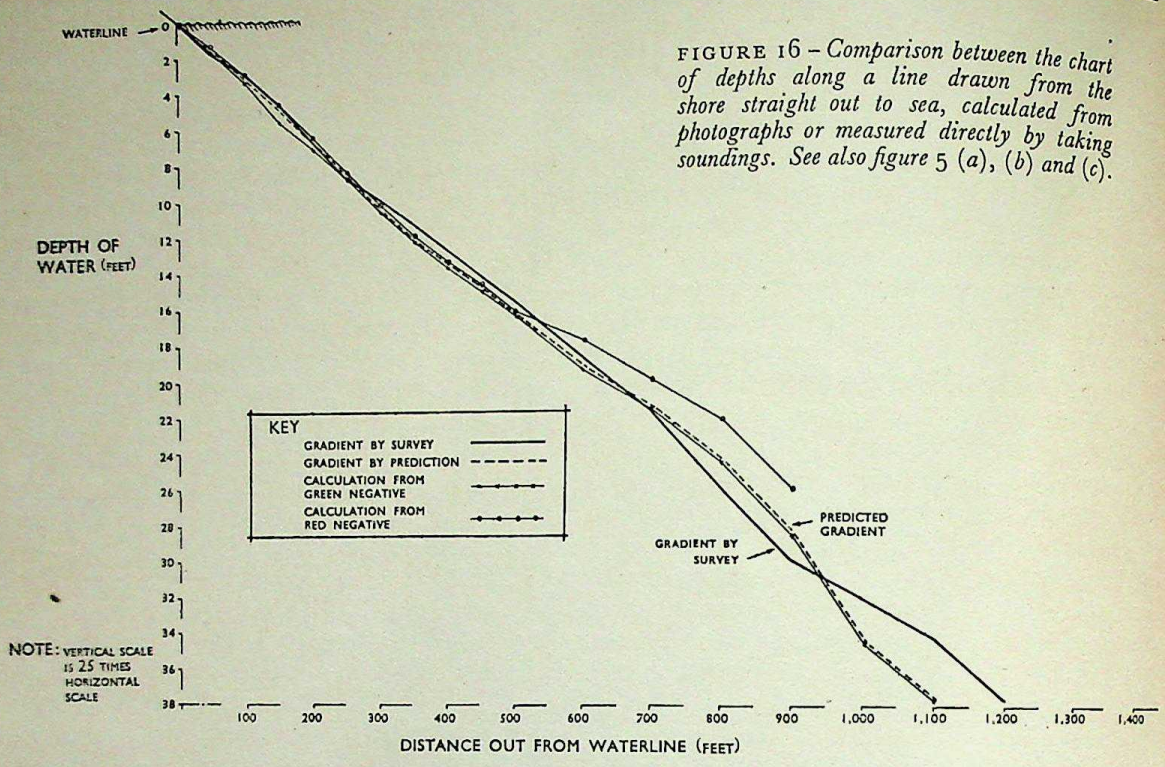

FIGURE 16 – *Comparison between the chart of depths along a line drawn from the shore straight out to sea, calculated from photographs or measured directly by taking soundings. See also figure* 5 (*a*), (*b*) *and* (*c*).

particular trees such as teak or wild rubber estimated.

There is another wartime technical development which has a certain contribution to make to vegetation surveys and similar projects. This is the moving-film camera, in which the film can be moved during the exposure so as to compensate for the movement of the image caused by the speed at which the aircraft is travelling. This compensation is of importance only when high-speed aircraft are travelling rather low down. With this system it is possible to take sharply focused vertical photos at such large scales that they eliminate the need for any checking on the ground of the accuracy with which the usual small-scale photos have been interpreted (figure 14). This has great advantages in inaccessible country. If, for instance, one wishes to be certain of the different species of trees in a region like that shown in figure 11, it would be tedious to have to send an expedition to verify the photo-interpretation; but the job could be done quite quickly with a low-level, vertical photograph of this kind.

There has been space to mention only a few of the uses of aerial photography for peaceful purposes. Those which have been chosen for illustration are those which can be most generally applied to almost any region of the earth. Many other applications have been made more locally. For instance, in some countries aerial photos clearly show the boundaries of different soil areas. In some parts of the world, particularly uncultivated countries, a great deal of geological information can be deduced from them, and rough geological surveys can be made with a minimum of ground work. There have also been many quite local problems where air survey has been extremely valuable—for siting reservoirs, power cables, roads, and so on. Much use has also been made of the method in archaeological work for discovering the position and extent of ancient fortifications, circles, burial mounds, and other artifacts. It would take too long to try to enumerate all these possibilities, and in any case the list would certainly be incomplete. Enough has been said to show that in aerial photography we have another technique which can supplement ground mapping with new applications of as wide, though somewhat different, a scope.

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The spectroscopy of flames

R. F. BARROW

Flame spectra are very complex, and it is only since the development of quantum theory that substantial progress towards their elucidation has become possible. Difficulties may arise owing to the necessity for distinguishing between chemiluminescent and thermal phenomena. Dr Barrow here reviews recent work, and makes the interesting point that chemiluminescence may in the future have an important part to play in lighting systems.

Recognition of spectroscopy as a valuable tool for investigating the nature of flames dates from the work of Bunsen and Kirchhoff, published in 1859. Their fundamental observation that elements are characterized by spectral lines of definite wave-length stimulated the empirical study of spectra, of which the most striking results were the discovery of new elements and Crookes's identification of Lockyer's line in the solar spectrum with that derived from terrestrial helium. Such line spectra were attributed to emission of light from atoms, and band spectra to emission from particles of greater complexity, but in the latter case experimental evidence was by itself insufficient to identify the emitters unambiguously. The interpretation of band spectra had to await quantum theory, the application of which to the analysis of the spectra of simple molecules, particularly those consisting of only two atoms, was finally worked out in the period 1925–35.

The study of flame spectra followed this general development, so that the earlier work was directed mainly towards identification of atomic and molecular species. The results of this work were somewhat surprising. It was manifest that flames consist of mixtures of reacting gases, sometimes with dispersed solid smokes, often at fairly high temperatures. That they contain unusual chemical species was evinced by their electrical conductivity. That certain atomic spectra, for example those of the alkali and alkaline earth metals, were found to be of frequent occurrence was not unexpected. The vapours of these elements were known to be largely monatomic, and the actual atomic concentrations required for light emission were found to be exceedingly small. What was at first remarkable was the nature of the molecular species identified—unstable radicals, unknown to the chemist under ordinary conditions, such as C_2, CH, and OH. Analysis of the fine structure of their spectra, however, left no doubt of the correctness of their identification, while at about the same time their existence under such conditions became more readily credible as workers in the field of chemical kinetics found it necessary to postulate their participation in photochemical and thermal chain reactions.

Apart from the line and band spectra, which may be characterized, if not always in the latter case immediately identified, by wave-length measurements, many flames emit continuous spectra the elucidation of which necessarily requires more subtle experimental investigation. Such continua may arise either from incandescent solid particles present in the flame or from a variety of atomic and molecular processes, some of which will be considered later.

The first problem in the study of flame spectra must always be the identification of the emitting species. This often presents experimental difficulties which increase with increasing weight and complexity of the emitter. Even in diatomic spectra the only certain methods depend either on rotational analysis, which gives information about the molecular quantum numbers and the interatomic distances, or on comparison with absorption spectra obtained under clearly defined chemical conditions. Both methods are subject to limitations. Rotational analysis requires the use of large spectrographs of high resolving power, but the amount of light available in flames is frequently very small, so that the necessary length of exposure may be almost impracticable. In addition, in presence of the continuous radiation which so frequently accompanies the discrete spectra, it may be difficult to secure adequate contrast of the structure lines on the photographic plate. The method of comparison with absorption spectra is of course confined to those systems which involve the ground electronic state of the radical concerned (which is, however, very often in this state), and to those species which are of not

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too great chemical instability. In spite of these difficulties it has been possible to identify with certainty a high proportion of the diatomic radicals whose spectra occur in flames, and indeed, owing to their particular excitation characteristics, the reverse process has sometimes been employed, i.e. flames are sometimes useful sources for the spectroscopic examination of molecules which do not appear to emit light readily under other experimental conditions.

The difficulties of identification are greatly multiplied in the flame spectra of radicals or molecules containing more than two atoms. In place of the definite answers which spectroscopy can give about atomic and diatomic emitters, the identification of the substances responsible for electronic band systems of polyatomic molecules is much less certain. It then generally becomes necessary to take into account more ambiguous evidence, relating for example to the probable concentrations of transitory intermediates. At least three such systems—the carbon monoxide and hydrocarbon flame bands and the ammonia α-band—are of some importance in connection with theories of combustion, and it is unfortunate that in no case is the identity of the emitter immediately demonstrable.

The spectrum of the flame of carbon monoxide burning in air or oxygen consists of a faint system of bands superposed on a strong, continuous background which extends through the visible and near ultra-violet regions of the spectrum, and is strongest in the range 3,500–4,500 A. It has been concluded that the emitter is probably carbon dioxide [1], [2].

The ethylene, or hydrocarbon, flame bands, which lie in the range 2,500–4,500 A, are associated with the flames of burning hydrocarbons: they occur, for instance, in the inner cone of the ordinary Bunsen flame, and were first described in detail by Vaidya [3]. Gaydon has studied this spectrum recently [4], and has shown that its production runs parallel with the formation of peroxides in the flame. Like Vaidya, he assigns the bands provisionally to HCO, but remarks that alternative emitters cannot be entirely ruled out.

The ammonia α-band, a complex 'many-lined' spectrum, appears in the oxy-ammonia flame, and is responsible for its yellow-green colour. It has been ascribed by Rimmer [5] to NH_2.

The study of continuous spectra has been somewhat neglected by spectroscopists, perhaps naturally enough in view of the abundance of discrete spectra to be photographed and analysed, but as a result of this preoccupation there is surprisingly little quantitative information available about continua. And it is quantitative information which is now in question, for the only means of characterizing such spectra precisely is by way of data giving the intensity of the continuum as a function of wave-length, i.e. of energy. Before discussing any individual examples it will be as well to consider briefly some of the possible mechanisms by which light can be produced in flames.

The ultimate aim of quantitative spectroscopy is to relate the intensity to the probability of the particular event leading to light emission at a given wave-length and the number or numbers of particles involved in that act. The general formulation of this problem was given by Einstein. Considering the transition from an excited state 1 to the ground state 0, for the total energy emitted per unit time per unit volume, $\bar{S}_{1,0}$ we have:

$$\bar{S}_{1,0} = \mathcal{N}_1 . h\nu_{1,0} . A_{1,0}$$

where $\nu_{1,0}$ is the frequency of the light emitted,
$\mathcal{N}_1$ is the number of atoms or molecules per unit volume in state 1, and
$A_{1,0}$ is the 'transition probability,' which is often given simply by the reciprocal of the life-time in the excited state, τ_1.

The processes responsible for light production can be divided broadly into two classes: (*a*) thermal excitation, and (*b*) chemiluminescence, and we will take these in turn.

It appears probable that, in many flames at least, the mechanism of light emission by radicals or solid particles is due merely to collision with charged or uncharged molecules or with atoms possessing high thermal energies. On a simple view, if we assume that temperature equilibrium is established for the different modes of energy intake, we can apply the Boltzmann distribution law to get the number of particles in the upper state $\mathcal{N}_1$, and we find that there should be an exponential dependence of $\bar{S}_\lambda$ (the value of $\bar{S}$ at some wave-length λ) upon absolute temperature T of the form $\bar{S}_\lambda = C.e^{-h\nu/kT}$, where C is a constant. The interest of this expression is that, although it is experimentally very difficult to measure absolute values of the intensity—indeed reliable measurements have been made for only a few atoms and for one or two diatomic molecules such as OH and CN—we can get relative intensity values without too much difficulty, and such data provide the basis of the spectroscopic methods of temperature determination.

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For this, the distribution of molecules among either vibrational, or, better, rotational, states may be used. Alternatively, and far more conveniently, the line-reversal method can be employed. The principle of this is as follows. The reversal of spectral lines, e.g. the sodium *D* lines excited by adding small amounts of a sodium compound to the flame, is examined in a visual spectrograph against a background of variable brightness such as may be obtained from a tungsten strip filament lamp. When the lines just merge into the continuous background the flame and the continuous source are at the same black-body temperature, which may be measured on the latter with an optical pyrometer. It should be mentioned that there has been some criticism of this method, directed against its basic assumption that the atomic radiation is purely thermal, but that it does apply in a fair number of cases is shown by data quoted, for example, by Jost [6].

The variation of the intensity of emission with wave-length at a constant temperature is, of course, different for different cases. A continuum arising from incandescent particles would obey Planck's distribution law for black-body radiation—or rather the law as modified for a grey body, taking into account the departure from unity of the emissivity of the particles. Unfortunately, emissivity data, except for a few technically important substances, are rather meagre. In the case of discrete or continuous light emission arising from a transition between two electronic states, the wave-length distribution of intensity will depend upon the relative disposition of the potential energy surfaces in upper and lower states (Franck-Condon principle), on the statistical weights of these and of the sub-states, and on the Boltzmann distribution function for the upper state. Since the amount of energy available for thermal excitation in ordinary flames is comparatively small, the discrete electronic systems observed almost invariably involve the ground state as the lower state of the transition. As has already been remarked, it is not yet possible to give any coherent picture of the continuous spectra of flames. One important type results from the recombination of an electron with a positive ion to form a neutral atom. A continuum whose origin seems to be still somewhat in doubt, but which is remarkable for its intensity, is that which appears more or less symmetrically disposed with respect to the resonance lines of sodium and potassium (and presumably the other alkali metals) when the metal is burned in oxygen or is introduced into a hydrogen-air flame or into the hollow cathode of a Schüler tube. Preliminary observations on the sodium-hydrogen-air flame suggest that the intensity is proportional to the concentration of alkali metal, and that it may have a temperature coefficient of the order expected for thermal excitation.

When a mixture of carbon disulphide and nitric oxide is exploded a brilliant flame is produced, which from the quantity of light emitted (apparently largely from the S_2 band spectrum) would correspond to black-body radiation at a temperature of about 5,000° K [7]. Again, under certain conditions, it is possible to get organic substances such as ether, acetaldehyde, and hexane to react with oxygen at rather low temperatures (200–400° C) with simultaneous emission of light. The latter flames have been photographed by Emeléus, and the spectra, which are all identical, have been shown by Pearse to be due to formaldehyde. It is clear that there is no direct relation between the temperatures of such flames and their luminosity, and it must be concluded that the light emission is due to some chemiluminescence process, whereby sulphur in the former case and formaldehyde in the latter are produced in excited electronic states. Let us briefly consider what might be expected of such a process.

The fundamental distinction between chemiluminescence and thermal excitation depends on the predicted numbers of excited species, N_1.† If, for example, a radical C is formed in an upper state by a chemiluminescence reaction

$$A + B \rightarrow C^*,$$

C^* thence falling back to the ground state with emission of radiation,

$$C^* \rightarrow C + h\nu,$$

then provided that deactivation processes of the type

$$C^* + M \rightarrow C + M$$

are unimportant, almost every C^* formed will radiate energy, instead of only the Boltzmann fraction of the stoichiometric concentration of species C, $e^{-h\nu/kT}$, for pure thermal excitation. Furthermore, in a chemiluminescence process, the effect of temperature on intensity will be determined by the activation energy of the reaction $A + B \rightarrow C$ (or by that of the rate-determining

†A clear experimental distinction between chemiluminescence and temperature radiation is by way of Kirchhoff's law, which states that at a given temperature the ratio of emissive power to absorptivity is constant and equal to the emissive power of a perfect radiator. This law is based on the assumption of thermal equilibrium and is therefore not obeyed by chemiluminescent systems.

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step in the cycle of events which leads to the production of A and B) rather than by the quantity $h\nu$.

The most thoroughly investigated reactions of this type are those between alkali metals and the halogens or halogen-containing compounds at low pressures in the dilute flames of Polanyi. In the case of sodium and chlorine an efficiency of about unity can be obtained for the light emission of the D lines. The most probable mechanism is:

$$\begin{aligned} Na \quad &+ Cl_2 = NaCl \quad + Cl \\ Na_2 \quad &+ Cl \quad = NaCl^* + Na \\ NaCl^* &+ Na = NaCl \quad + Na + h\nu \end{aligned}$$

where NaCl* refers to a sodium chloride molecule of high vibrational energy content.

The best-known example of a chemiluminescence continuum is again provided by the alkali metals and the halogens, for which recombination spectra due to processes of the type

$Na + Cl = Na.Cl^*$ (homopolar upper state)

$Na.Cl^* = Na^+.Cl^-$ (ionic ground state) $+ h\nu$

have been observed.

So far we have considered the bearing of chemiluminescence alone on electronic energy changes, but it appears also that thermal equilibrium may not always be attained for the other forms of energy intake. Thus the rotational temperatures of C_2 and CH in one and the same discharge through acetylene were found by Lochte-Holtgreven to be 4,700° and 2,000° K respectively. That this is not an unfair example is shown by the vibrational intensity data of Kondratjew and Ziskin [8] for a hydrogen-oxygen flame. They found that the (2, 1) band of the OH system was stronger by a factor of the order of 50 than it should have been had the vibrational energy distribution been thermal. Similar evidence that there is sometimes a delay in reaching equipartition for vibrational energy has been adduced from studies of vibration-rotation bands in the infra-red.

It is of considerable importance to establish whether or not the vibrational or the electronic energy is chemiluminescent or thermal in origin. If chemiluminescence processes obtain, then clearly the scheme postulated for the overall reaction must make provision for the formation of such species in excited levels. It would take us too long to consider any one case in detail—even the mechanism put forward for the burning of hydrogen in oxygen to form water is a formidable affair—but it is worth noting that in this reaction the spectroscopic evidence that the OH emission must be chemiluminescent is of considerable value in assessing the relative importance of some of the different reaction steps suggested.

This question has also a very direct bearing on practical problems of light production. It has already been mentioned that the emission from the carbon disulphide-nitric oxide flame corresponds in efficiency to a black-body radiator at about 5,000° K. It has been calculated to be about 83 lumens/watt. 5,000° K is, of course, an impracticable temperature for a terrestrial flame. If we take 2,000° K as a reasonable figure, we get an efficiency of light production of only 1·7 lumens/watt, so that the chemiluminescent source is, on an energy basis, some fifty times as efficient as an ideal black-body source at 2,000° K. So far, no one has succeeded in developing any such chemiluminescent source on any considerable scale.

Finally it should be noted that spectroscopic measurements in absorption provide us with the possibility of determining the concentrations of radicals. This may be done directly to determine stationary concentrations in flames, but what is probably of greater interest is the possibility of observing changes of concentrations with time in discharges, and thus exploring the kinetics of their production, decay, and transfer of energy. Such studies of radical kinetics are difficult, and the results are not necessarily immediately applicable to the radical reactions occurring in flames, but they should nevertheless form an increasingly valuable supplement to data derived from the more orthodox methods of chemical kinetics.

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Molecular sedimentation in the ultracentrifuge

THE SVEDBERG

The sedimentation of particles of molecular dimensions can be experimentally observed if the equivalent of an intense gravitational field is produced by centrifugal force. The necessary conditions can be created in an apparatus known as the ultracentrifuge. The latter has proved particularly useful in the study of the homogeneity of proteins and the determination of their molecular weights. The technique has also been successfully used in the study of other natural and synthetic polymers such as cellulose, rubber, and polyethylenes.

The sedimentation or settling of small particles under the influence of gravity is an everyday phenomenon which plays, and has played, a great part in geophysics. Clay deposits, old and recent, are formed through the fractionating effect of the sedimentation of particles carried by the water of streams and rivers to the lakes and the ocean. With decreasing size of particle the sedimentation becomes slower and slower, until the inevitable thermal convection currents stop it altogether. The greenish colour of many glacier lakes is due to minute particles floating in the water.

If the size of the particles is further diminished, to molecular dimensions, another phenomenon comes into play, namely the diffusion or irregular thermal motion of the individual particles or molecules. The atmosphere surrounding the earth is kept from flying away into planetary space by sedimentation, and is prevented from settling down as a dense layer on the surface of the earth by diffusion. The state resulting from this combination of sedimentation and diffusion is called sedimentation equilibrium. If we want to use the sedimentation of molecules for analytical purposes in the laboratory, the force of gravity has to be increased hundreds of thousands of times. This can be accomplished by means of swift rotation in a specially designed centrifugal apparatus, the so-called ultracentrifuge.

The first measurements of molecular sedimentation were performed at Upsala in an oil-turbine ultracentrifuge constructed for that purpose. Since then other types of ultracentrifuge have been devised, using compressed air or electric current of high frequency as the driving agent. Whatever the driving force, the solution to be studied has to be enclosed in a small cell of sectorial shape with windows for optical measurements. This cell has to be mounted in a rotor spinning at constant temperature in hydrogen at low pressure, or in a perfect vacuum (figure 1).

Particles or molecules in a centrifuge travel towards the periphery along radii, hence the sectorial shape of the cell. Constant temperature has to be maintained in order to avoid disturbing convection currents. In the case of the oil-turbine ultracentrifuge the rotor is provided with two small turbines, one at each end of the shaft, acted upon by oil under pressure. To avoid vibration the rotor and its cell are carefully balanced, and the bearings are provided with a special damping device. A solid steel casing protects the observer and instruments in case of failure of the rotor material (figure 5).

The methods of observation used so far are based on either the absorption or the refraction of a beam of light passed through the rotating cell. The former is more direct and easier to understand, the latter more precise (figures 2 and 3).

In the former case each molecular species shows up as a step on the curve, in the latter as a peak. By such methods the molecular composition of a solution can be studied. If only a few molecular species are present, each of them of definite mass and shape, the analysis is comparatively easy. This is the case with many of the native proteins. Other substances of high molecular weight, such as the polysaccharides, consist mostly of molecules of continuously varying size. In the sedimentation diagram this shows up as a marked broadening of the peak (figure 4).

There is always a certain degree of broadening due to the diffusion or thermal motion of the molecules, but it is much slower in the case of large molecules such as those of cellulose. For comparison with the sedimentation peaks, a pure diffusion peak resulting from the blurring of a

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boundary between a solution of cellulose and pure solvent is shown in figure 6.

The time required for the broadening was here fifty hours, while in the case of sedimentation broadening due to the unequal size of the molecules the time was only fifty minutes.

The unequal size of the molecules—the so-called polydispersity—shows up in the diffusion curve in a peculiar way. For a solution containing only one molecular species the broadening of the curve follows the simple statistical laws. In the case of a mixture, however, there is a marked deviation (see figure 6). As a comparison, figure 7 gives the diffusion diagram for a monodisperse substance, serum albumin, and figure 8 the sedimentation diagram for the same molecules. Here the broadening of the sedimentation peak is entirely due to diffusion, and the diffusion follows the simple statistical laws. The molecular weight can be calculated from sedimentation and diffusion according to the formula:

$$M = RTs/\{D(1 - V\rho)\}$$

where M = molecular (or particle) weight,
R = gas constant,
T = absolute temperature,
s = sedimentation constant,
D = diffusion constant,
V = partial specific volume of solute,
ρ = density of solution.

As already mentioned, the combined result of sedimentation and diffusion finally leads to a steady state, the so-called sedimentation equilibrium. The number of molecules per unit volume decreases exponentially in the direction of diminishing force. Thus the density of the atmosphere around the earth falls to half its ground-level value at an altitude of about 6,000 metres, while for a serum albumin solution exposed to a centrifugal field 10,000 times the force of gravity the corresponding distance is only 1 mm.

Owing to the fact that sedimentation equilibrium is dependent upon both sedimentation and diffusion, the molecular weights can be found directly from such determinations by means of the formula:

$$M = \frac{2RT \cdot \log(c_2/c_1)}{(1 - V\rho)\omega^2(x_2^2 - x_1^2)}$$

where c_1 and c_2 are the concentrations at the distances x_1 and x_2 and ω is the angular velocity.

The measurement of molecular sedimentation by means of the ultracentrifuge has proved a very useful analytical tool in many branches of science, medicine, and industry.

The blood of all vertebrates and many invertebrates contains a variety of respiratory pigments, either enclosed in corpuscles or simply dissolved in the blood-fluid. The bluish haemocyanins of the snails and crustaceans have molecular weights of the order of millions. Many of these types of molecule undergo dissociation reactions when the environment is changed, resulting in a splitting of the molecule. The reactions are often characteristic of the genus and species.

Thus the haemocyanin in the blood of the snails *Helix* is stable only within a certain *p*H range. Outside this region the molecule is dissociated into well-defined cleavage products with molecular weights one-half and one-eighth that of the original molecule. The parts have the same length as the parent molecule. The haemocyanin of *Helix pomatia* can also be split by the addition of salt. Curiously enough, only three-quarters of the molecules present are sensitive to salt; the rest remain undissociated. Evidently there are two chemically different kinds of haemocyanin molecules present in the blood of *H. pomatia*: one is split both by *p*H change and addition of salt, the other by *p*H change only.

There is a second type of snail haemocyanin which is split by a change in *p*H but not by salt (example: *Paludina vivipara*), and a third type which is split only at extremely low and extremely high *p*H values and not by salt (example: *Buccinum undatum*).

The origin of the lowest class of the vertebrates possessing red corpuscles, the *Cyclostomata* (lamprey and hagfish) has long been a question of controversy among taxonomists. The opinion now generally accepted looks upon these worm-like fishes as belonging to a very ancient side branch on the genealogical tree of the vertebrates, far removed from other living animals. The determination of the molecular weight of the red blood-pigment for the various groups of vertebrates by means of the ultracentrifuge gave the result that all vertebrates, including the different types of fish, with the exception of the *Cyclostomata*, show a value of about 69,000; the *Cyclostomata*, however, give a value of only one-fourth of this, or 17,500. Sedimentation analysis, therefore, strongly supports the result arrived at from morphological, anatomical, and palaeontological indications. To put it crudely, man is more closely related to the salmon than the salmon is to the lamprey.

Many other instances of the use of molecular sedimentation analysis in taxonomy could be given, but only one more, from the field of botany,

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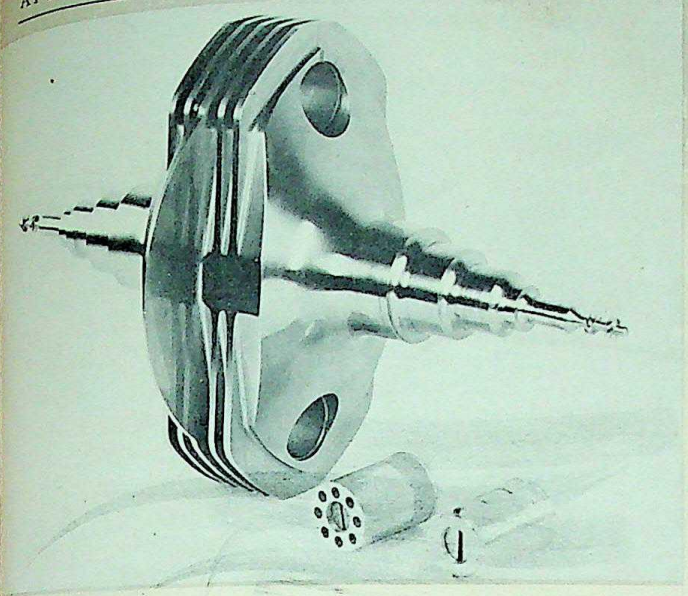
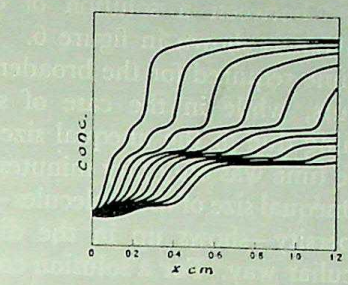


FIGURE 1 – *Rotor and cell for the oil-turbine ultracentrifuge. Beside the solution cell to the right is shown a cell for static and dynamic balancing.*



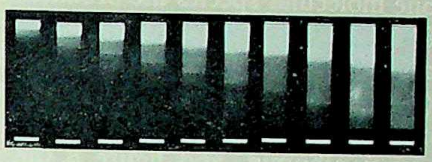
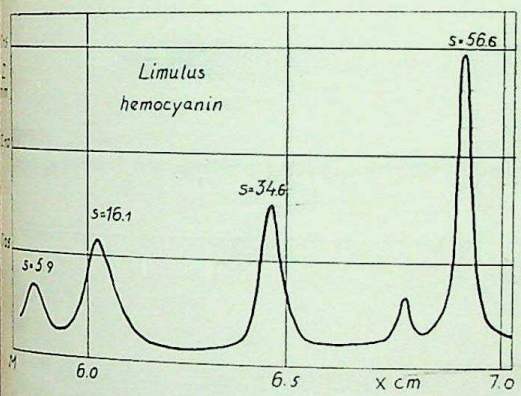


FIGURE 2 – *Sedimentation diagram of the protein molecules in the blood of the horse-shoe crab,* Limulus polyphemus, *taken by means of the light-absorption method.*



GURE 3 – *Sedimentation diagram of the same object taken by means of one of the refractive index methods.*

GURE 4 – *Sedimentation diagram of cellulose nitrate dissolved in acetone. (The cellulose used was a precipitated fraction of wood cellulose.)*

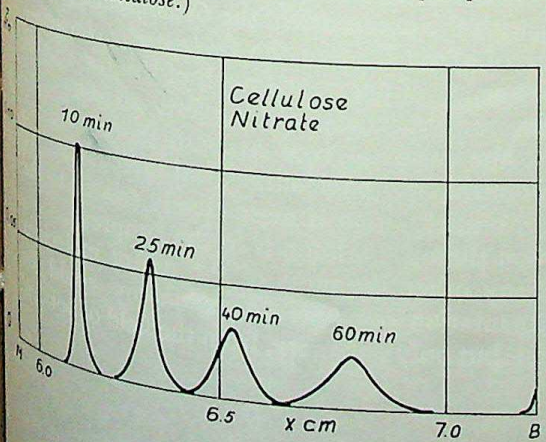
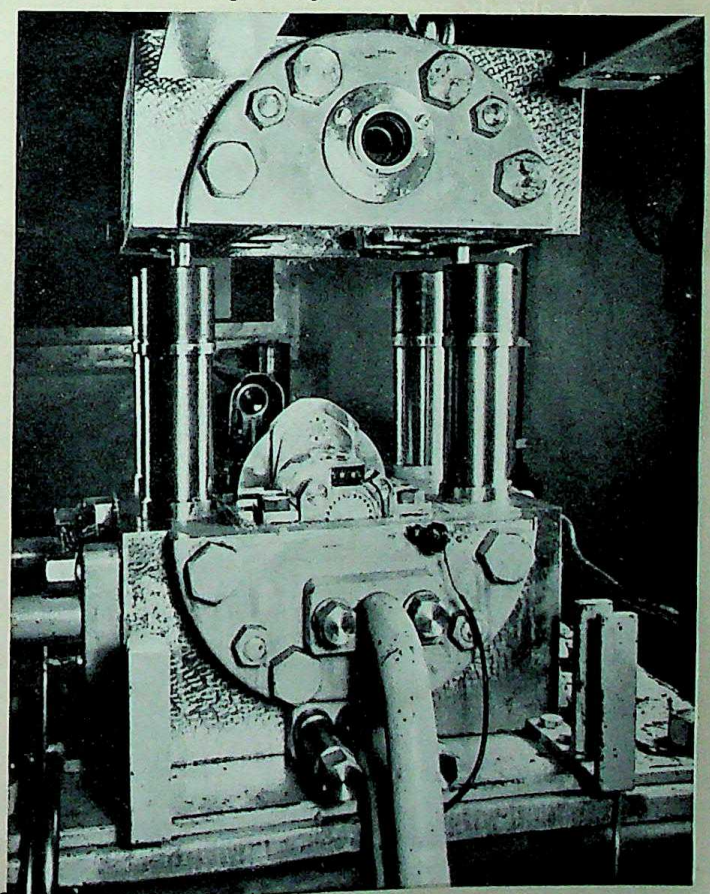


FIGURE 5 – *View of ultracentrifuge, showing the rotor in position and the heavy steel lid raised above the bolts which serve to hold the parts together.*



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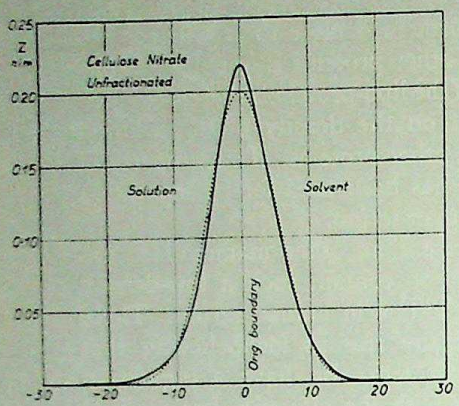

FIGURE 6 – *Diffusion diagram of cellulose nitrate dissolved in acetone. (An unfractionated sample of cellulose was used.)*

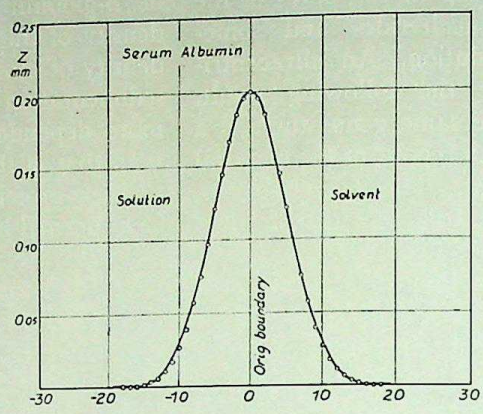

FIGURE 7 – *Diffusion diagram of serum albumin.*

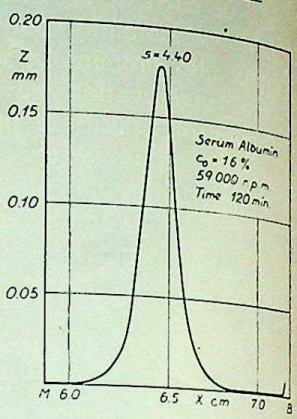

FIGURE 8 – *Sedimentation diagram of serum albumin.*

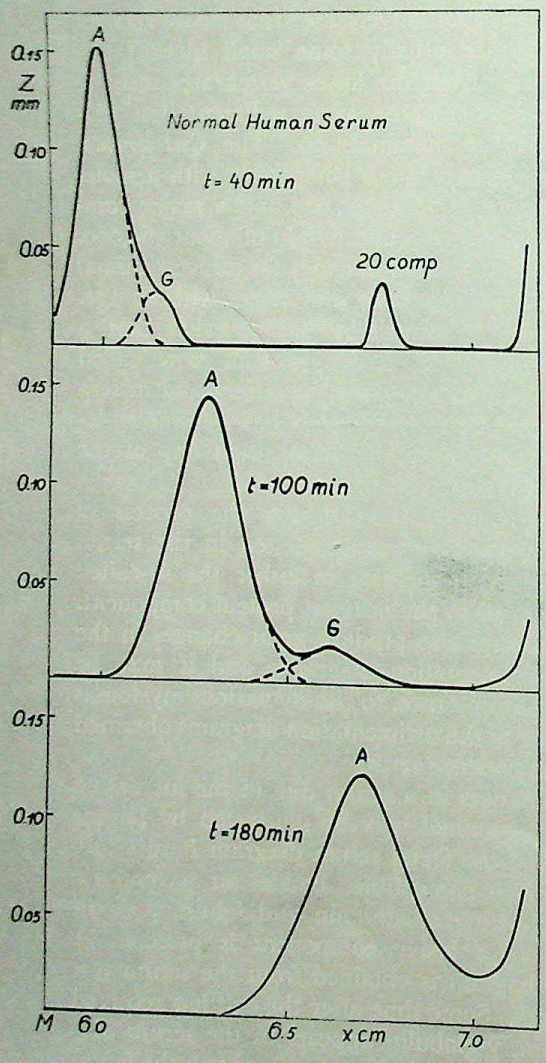

FIGURE 9 – *Sedimentation diagram of normal human serum, showing three peaks (A, G, and 20-comp.). See page 93.*

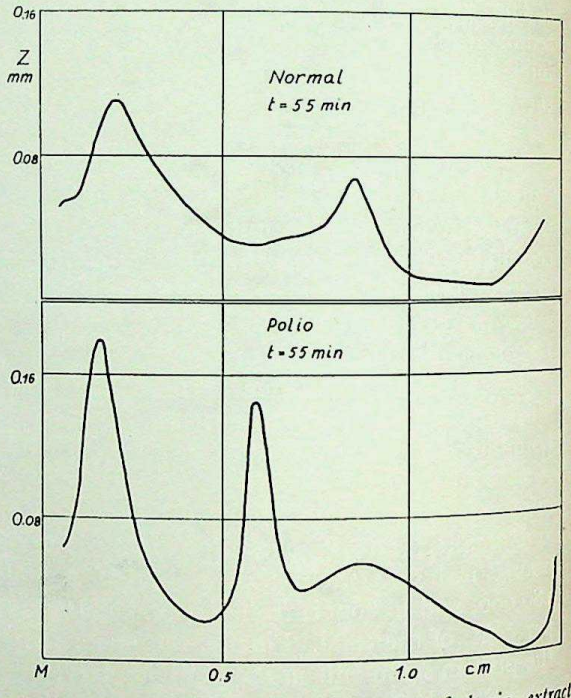

FIGURE 10 – *Sedimentation diagrams of brain extract containing poliomyelitis virus and other high-molecular proteins and of virus-free brain extract.*

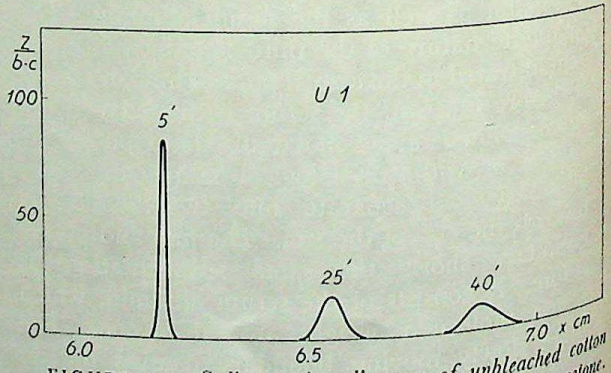

FIGURE 11 – *Sedimentation diagram of unbleached cotton linters which have been nitrated and dissolved in acetone. The molecular weight (m.w.) is 1·9 millions, corresponding to a degree of polymerization (d.p.) of 6,000.*

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will be cited here. The sap in the bulbs of the *Liliiflorae* contains polysaccharides and sometimes also proteins in solution. An ultracentrifugal investigation gave the following result. Among the species of the same genus there is a pronounced similarity with regard to the material of high molecular weight. The *Lilium* species, for instance, contain a large amount of polysaccharide, while species of *Fritillaria* and *Tulipa*, belonging to the same subfamily as *Lilium*, contain more protein than carbohydrate and show sedimentation diagrams quite different from those of *Lilium*. There is one very interesting exception: *Fritillaria kamchatkensis*, which is closely related to the *Lilium* (and which has been placed by some taxonomists within this genus), yields a diagram of the *Lilium* type.

The medical applications of ultracentrifugal sedimentation are numerous. One of the most interesting examples is the disentanglement of the complicated protein system of the blood-plasma. Normal serum shows three boundaries (see figure 9). The first one, the so-called 20-component fraction, sediments to the bottom of the cell in about forty minutes under standard conditions (room temperature and 250,000 times gravity). In concentration it corresponds to only a few per cent. of the total protein in the serum. Its molecular weight is of the order of half a million. At the same time as the first boundary reaches the bottom of the cell, a second broad boundary has usually just separated from the top of the solution. As it moves towards the periphery it eventually splits into two boundaries. The first, and smaller, one reaches the bottom in 1½–2 hours; it has a molecular weight of 150,000–180,000, and in concentration it amounts to 10–20 per cent. of the total. Finally, the major part of the protein sediments in the last boundary, which reaches the bottom of the cell in about three hours. This boundary, however, does not correspond to a single substance, but represents a protein called β-globulin as well as the serum albumin. The composite nature of the third boundary is easily demonstrated in the case of normal human serum. If, before the run, the serum is diluted with an equal volume of 0·2 molar disodium phosphate instead of with physiological saline, the third boundary will separate into two boundaries towards the end of the run. The first and bigger boundary shows the same sedimentation as before. It consists of the serum albumin, which has a molecular weight around 70,000. The more slowly moving boundary consists mainly of β-globulin, which is a lipo-protein. The density of this protein is close to 1, whereas the density of most other proteins is about 1·3. The sedimentation of the lipo-protein is therefore much more dependent on the density of the solution than that of the other proteins. This property of the lipo-protein has been used for its separation from normal human serum.

Up to the present no other mammalian sera have been found to contain such a low-density lipo-protein as the one in human serum. There are, however, many reasons for believing that other mammalian sera also have a β-globulin which sediments with the albumin, but its lipid part has a higher density than the human one.

The general appearance of the sedimentation diagram from normal adult mammalian serum seems to be qualitatively the same for all species, but there are usually some small quantitative differences. Even the lower vertebrates seem to give qualitatively the same sedimentation diagrams as the mammals do. The *Cyclostomata*, however, have a minor component with a molecular weight of about 35,000 and a major component with a molecular weight of about 360,000.

The sedimentation diagram for a given animal is not always the same, but varies with its age. Thus the ultracentrifuge has revealed that a hitherto unknown serum protein, now called fetuin, is present in many foetal sera and in sera from newly born animals. It has a lower molecular weight (around 50,000) than any of the previously isolated serum proteins.

Antibody production during the process of immunization is often manifested in the serum diagram as an increase in either the so-called γ-globulin or in the heaviest protein component. Some diseases also produce great changes in the serum sedimentation diagrams, and it may be possible, for instance, to classify various myelomas according to the sedimentation diagrams obtained from the patient's serum.

The changes in a serum due to the increasing age of the animal may be illustrated by bovine serum. In the foetal serum diagram hardly any γ-globulin is perceptible. Besides an asymmetric peak consisting of albumin and fetuin, a small amount of a heavy component is present. A similar diagram is obtained from the serum just after birth. Some time after the calf has received colostrum, γ-globulin appears in the serum diagram. During the first weeks after birth the fetuin and the γ-globulin decrease. Later the fetuin practically disappears, whereas the γ-globulin

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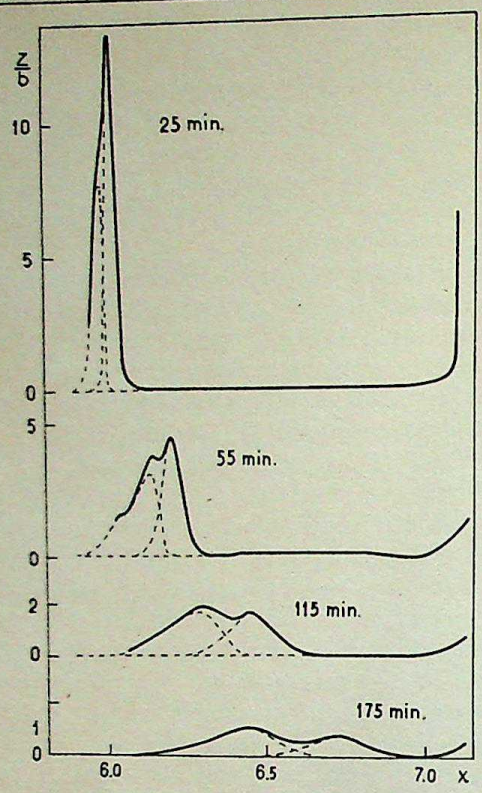

FIGURE 12 – *Sedimentation diagram of native wood cellulose obtained by extraction with cuprammonium. Two maxima are to be seen, one representing the cellulose proper (m.w. = 700,000, d.p. = 4,300) and the other wood polyoses (hemicellulose).*

increases, when the natural immunity is being built up, until it reaches its 'natural' level.

Another medical application is in the study of viruses. Directly after the first preparation of virus crystals (tobacco mosaic) the analytical ultracentrifuge was used for the determination of the mass of these huge molecules and to compare various strains of virus. A great number of such determinations have been made during the last ten years.

Sedimentation measurements in the ultracentrifuge have proved very useful as a means of following the process of purification of a virus. As an example, the isolation of poliomyelitis virus from brain tissue or intestinal contents may be mentioned. In figure 10 are given the sedimentation diagram of brain extract containing both virus and other high-molecular proteins (three peaks), as well as a control diagram of the virus-free brain extract.

Many industrial problems concerning material of high molecular weight belonging to the polysaccharides and to various groups of synthetic organic polymers have been studied by means of ultracentrifugal sedimentation. The most important of the macromolecular carbohydrates, from a technical point of view, is cellulose. It occurs in a fairly pure state in certain fibres such as cotton and flax. Native cellulose, however, generally occurs in combination with other carbohydrates and with lignin, and its liberation requires rather drastic chemical treatment (the sulphite and sulphate processes).

For many purposes the industrially prepared cellulose should contain molecules consisting of the longest possible chains of glucose groups, and it is often considered advantageous that the length of the individual molecules should be nearly equal (monodisperse). In the industrial processes for isolating cellulose from wood a considerable degradation takes place, especially during the later stages. The chain molecules break, and shorter and more unequal (polydisperse) pieces result. It is of considerable importance to find the most favourable conditions for producing a cellulose of a specified molecular type. Investigations of this kind have been carried out by means of the ultracentrifuge. An example of a comparatively monodisperse cellulose of very long chain molecules is given in figure 11. Native wood cellulose, on the other hand, is much more polydisperse (figure 12).

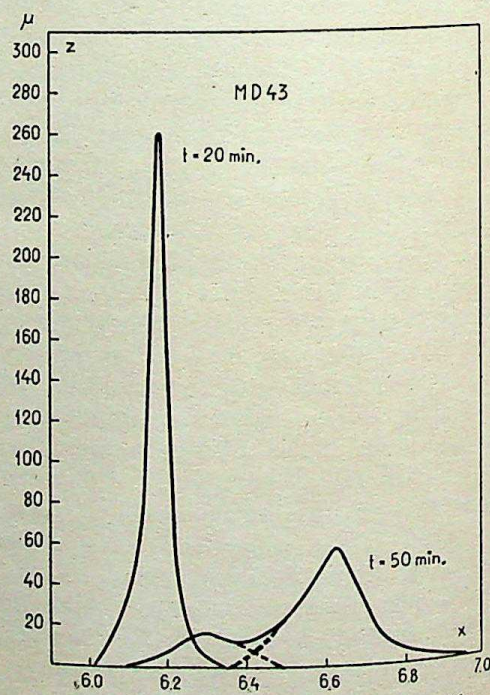

FIGURE 13 – *Sedimentation diagram of sulphite cellulose nitrated and dissolved in acetone (m.w. = 530,000, d.p. = 1,850).*

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Industrial wood cellulose manufactured according to the sulphite process is broken down considerably, and the amount of wood polyoses is diminished (figure 13).

In such cases as cellulose, where the broadening of the sedimentation curves is caused entirely by the different rate of sedimentation of the individual molecules, a measure of the polydispersity is obtained by calculating dB/dx, the rate of broadening with increasing distance from the centre of rotation (cf. figure 4).

The complete description of a polydisperse material such as cellulose requires the determination of the distribution or frequency curve for the weights of the molecules. This problem is very difficult, and so far only approximate solutions have been found. In figure 14 are given the frequency curves for two commercial cellulose materials, computed from sedimentation data.

Among the synthetic high polymers and their natural prototypes rubber plays an important role. The technical value of various types of rubber depends to a considerable extent upon the size and shape of the molecules. Here sedimentation analysis in the ultracentrifuge has furnished valuable information. In the case of neoprene it was found that bulk polymerization gives molecules of simple chain type, while certain kinds of emulsion polymerization produce molecules of a more branched type. For most purposes it is desirable to obtain a rubber with simple chains, and therefore the polymerization process should be conducted in such a way as to yield that type of molecule. Also in the case of plastics, such as polystyrene, methyl methacrylate, and other polyethylenes, the ultracentrifuge has been used for the control of industrial processes.

Above I have tried to indicate how by means of studying molecular sedimentation we have been able to collect a wealth of facts concerning material of high molecular weight, both native substances built up within the living organism such as proteins and carbohydrates, and artificially produced macromolecular substances such as plastics. The ultracentrifugal method is, however, by no means the only one for the study of these problems. There are also electron microscopy, X-ray analytical methods, osmotic methods, diffusion measurements, viscosity methods, and so on.

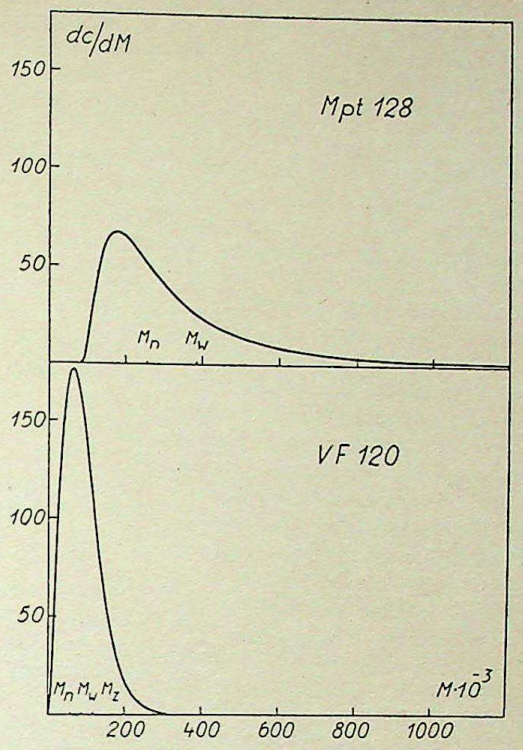

FIGURE 14 – *Frequency curves for two different cellulose materials nitrated and dissolved in acetone.*

Book reviews

ODYSSEY OF A BOTANIST

A Botanist in Southern Africa, by John Hutchinson. Pp. xii + 686, with numerous photographs, drawings, and maps. P. R. Gawthorn Limited, London. 1946. 45*s. net.*

This is a fine book, and one cannot do justice to it in a short review. The illustrations alone are a remarkable contribution to botanical literature, including numerous line drawings of living South African plants in Dr Hutchinson's well-known and most attractive style; a superb series of photographs which show many of the plants growing in their natural habitats; and various maps showing geographical distribution. The text takes the form of an account of the various journeys made by Dr Hutchinson and his companions, and of the plants which they encountered. There are sections on the floral regions of South Africa, the history of botanical exploration in the country, and allied matters, so that the book has the double value of a travel story and a student's handbook. There is a foreword by General Smuts, who figures largely in the book and who in fact made much of the work possible. The whole production is a monument to Dr Hutchinson's energy, botanical insight, and artistic skill; to the enterprise of Messrs Gawthorn, who published, at a very difficult time, an expensive book of a type which is too rarely seen in this country; and to the public spirit of General Smuts and other South African botanists.

T. A. STEPHENSON

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A HISTORY OF CHEMISTRY

Die Entwicklungsgeschichte der Chemie, *by H. E. Fierz-David. Pp.* 425. *Verlag Birkhäuser, Basel.* 1945. 21.50 *Swiss francs.*

This attractive book, with over a hundred illustrations, including portraits and reproductions from old books, is not a formal history of chemistry but is intended to interest and instruct chemists who have no opportunity of studying original sources. It deals with the origins of chemistry, alchemy, the period from Boyle to Lavoisier, the atomic and molecular theories, and the development of pure and applied chemistry in the nineteenth century. The author explains that he has not used original sources but has drawn his material from books, and in some cases he does not seem to have made use of more recent publications which would have been helpful to him. The collection of miscellaneous book titles in the appendix serves no useful purpose, and could have been replaced by a list of books on the history of chemistry which would have supplied the many gaps in the story now presented. Although the text is generally accurate and informative, there are lapses, as when Faraday is put before Berzelius in the development of the electrochemical theory, and in the account of the theory of valency Frankland is not mentioned. The author has managed to cover a large field in an interesting manner, and all chemists who read German will find the book attractive. To the historian of chemistry it will be less useful, but the author does not claim to have had his requirements in mind. The references, however, will disclose some interesting features even to the expert, and the book is one which should find its place in the field of historical works.

J. R. PARTINGTON

PHYSICS AND PHILOSOPHY

Fundamental Theory, *by Sir A. S. Eddington. Pp. viii* + 292. *University Press, Cambridge.* 1946. 25*s. net.*

There will be few (and an experimental physicist cannot be expected to be among them) who will be able to understand in full detail all the profound and subtle arguments developed in this remarkable posthumous treatise on the fundamental particles and constants of nature, which is edited by Sir Edmund Whittaker. Eddington investigates the way in which structures are related to the uncertainty constant of the frame of reference, and already by page 10 obtains a simple relation between the range constant of nuclear force and the speed of recession of nebulae, thus straddling physical concepts from the atomic nucleus to the cosmos.

The book is rich in brilliant analogy and is enlivened by unexpected flashes of humour, despite its profundity. Important concepts developed include the replacement of gravitation by a 'mechanical' exclusion principle corresponding to the 'electrical' exclusion principle of Pauli. Eddington's now well-known epistemological theory for the number of particles in the universe is linked up with the general derivation of atomic constants. By adopting experimental values for three natural constants other atomic constants can be obtained, the agreement with observation being startling. To select two examples only, (*a*) fine structure constant; observed = 137·009, theoretical = 137; (*b*) ratio of masses proton/electron; observed = 1,836·27, theoretical = 1,836·34. The theory, among other matters, also predicts the existence of mesotrons of respectively 174 electron masses and 2·38 proton masses.

Only time can decide the ultimate importance of this outstanding contribution to physics and philosophy.

S. TOLANSKY

FREE RADICALS

The Chemistry of Free Radicals, *by W. A. Waters. Pp. viii* + 295. *The Clarendon Press, Oxford.* 1946. 20*s. net.*

Free radicals were at one time little more than chemical curiosities, yet the essential part which they play in many of the familiar reactions of organic chemistry can be judged by the very wide scope of this book, which appears at a most opportune moment. It is still possible in a single volume to give a comprehensive account of this rapidly expanding subject. Some of the earlier ground is well known, e.g. the discovery and properties of the radicals of the triphenylmethyl and diphenyl nitrogen types.

Chapters in the book are devoted to the parts played by free atoms of hydrogen, oxygen, chlorine, and sodium in gaseous reactions and photochemical decompositions. The author deals also with reactions which are catalysed by free radicals, including halogen atoms, peroxide catalysed reactions, and the chain polymerization of olefines. Of particular interest are the chapters dealing with free alkyl radicals and their reactions in solution, and with the production and properties of the free aryl radicals generated in solution by the decomposition of diazo compounds, to our knowledge of which the author has himself made outstanding contributions. The final chapters deal with reactions involving metals as free radicals, oxidation processes, and some possible applications of free radical chemistry to biochemical processes.

W. BAKER

RELAXATION METHODS

Relaxation Methods in Theoretical Physics, *by R. V. Southwell. Pp. vi* + 248. *Oxford University Press, London.* 1946. 20*s.* net.

Interest in relaxation methods for use in design and research is steadily growing as their power and range become more widely known. Many will be glad that, in addition to developing the methods, the author has taken the trouble to write a connected account of them for those who wish to understand, and even more for those who wish to use, them. Space forbids a description of the methods, but numerical solutions to a wide variety of problem, some of which still defy 'orthodox' analysis, are obtained, and are exhibited very clearly and with considerable detail in a series of diagrams. In each of the thirty-five specific problems solved the 'background' is skilfully summarized before computational details are given, so that the reader has a complete 'case-history' to enable him to treat with confidence and understanding similar problems which he may encounter. The author is to be congratulated upon an exposition orderly, lucid, and detailed, and the publishers upon the production of a very handsome volume at a very reasonable price. Nor must some credit be withheld from the research team, without whom, as the author generously admits, such a striking set of results could hardly have been obtained.

W. G. BICKLEY

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ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

VOLUME VI JULY 1947 NUMBER 23

Louis Pasteur

The fiftieth anniversary of the death of Louis Pasteur fell on 28th September, 1945, but at that time scientists of the world were too preoccupied with the immense task of reorganizing their work after six years of war to mark the occasion with the ceremony it deserved. Although Pasteur's researches were to a great extent in the fields of medicine and biology he was first and foremost a chemist and made many notable chemical discoveries, especially in the field of stereochemistry. His successes in biology and medicine were due in large measure to his application of chemical methods to these branches of science—a task which an earlier great French chemist, Lavoisier, would doubtless have essayed but for his untimely death. The present is a particularly appropriate time to recall Pasteur's life and work, for the centenary celebrations of The Chemical Society and the Eleventh International Congress of Pure and Applied Chemistry have at this time brought to London the greatest gathering of chemists that the world has ever seen.

Louis Pasteur was born at Dôle (Jura) on 27th December, 1822. His father was a tanner, who, appreciating the value of education, sent his son to be educated at Besançon, and in 1843 Pasteur was admitted to the *École Normale* in Paris. It was while working as an assistant in the laboratory of A. J. Balard at the *École Normale* that he made the fundamental discovery of molecular asymmetry, in 1848. In the same year he went to Dijon, and soon afterwards to Strasbourg, as a teacher. In 1854 he became professor and dean of the faculty of sciences at Lille, and in 1857 he returned to the *École Normale*, as director of scientific studies.

When he began his observations on tartrates in 1847, it was known that certain organic compounds in the liquid or dissolved state were capable of rotating the plane of polarization of polarized light, but no satisfactory explanation of the phenomenon had been advanced. Pasteur not only showed that the effect on polarized light was due to asymmetry of molecular architecture, but devised methods of resolving racemic mixtures. Indeed, his three methods of resolution—mechanical separation, separation by selective fermentation, and separation of derivatives formed with optically active reagents—are still, a century later, the only general methods available to chemists. For this brilliant work, by virtue of which he takes rank as the founder of stereochemistry, Pasteur was awarded the Rumford Medal of the Royal Society in 1856. In France, however, his first presentation as a candidate for the *Académie des Sciences* was unsuccessful, and his election was delayed until 1862.

At Lille, Pasteur's attention was attracted to the application of fermentation in the production of alcohol from grain and beet-sugar. He was thus led on to study the souring of beer, and in 1864 he extended his inquiries to the cause of sourness, bitterness, and ropiness in the celebrated rosy and tawny wines of his native Arbois. He examined under his microscope the micro-organisms present in good beer, and compared them with those of sour beer. In both he found yeast cells, but in the sour beer he found also other cells which on investigation proved to be responsible for the unpleasant taste. He showed that the growth of these harmful organisms could be inhibited by gentle heat, and thus introduced the process which we now call pasteurization. The application of pasteurization to milk has since become, as everyone knows, one of the principal methods of preventing the spread of tuberculosis. Pasteur also studied the process of vinegar-making and was able to suggest valuable improvements in this important industry.

Among the far-reaching results of Pasteur's

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biochemical work was his conclusive demonstration of the falsity of the theory of spontaneous generation, at that time still widely accepted. Somewhat surprisingly, Pasteur found his conclusions challenged, but he soon enlisted able supporters in Joseph Lister—who quickly perceived the great significance of Pasteur's work in his own field—and John Tyndall, the physicist. The Royal Society reaffirmed its confidence in him by electing him to membership in 1869 and awarding him the Copley Medal in 1874. The opposition eventually proved of value, however, for it led Pasteur to make new experiments, which so fully supported his earlier conclusions that they eventually proved unassailable.

From the study of micro-organisms which bring about the fermentation of wines and beers, Pasteur was led to the discovery of the bacterial causes of disease. This phase of his work began with his election to the *Académie de Médecine* in 1873. His candidature was opposed, and was approved by a majority of only one. Nevertheless, within ten years his work had introduced entirely new conceptions of the origin of certain diseases. In the years 1877–81 he made swift progress in this field. Much of his earlier experimental work (1865–8) was done with silkworms, for at that time the silk industry was in serious difficulties owing to the incidence of diseases which were destroying tens of thousands of the grubs. His work not only established his general theories but proved of immense practical value to the silk industry. From the diseases of silkworms he went on to the study of infectious diseases in general, and characterized many of the more important pathogenic bacteria. He discovered, too, the principles of inoculation by the use of attenuated strains of bacteria, thus placing the earlier work of Jenner on a logical basis. In this field his work on rabies, anthrax, and chicken cholera is particularly noteworthy. In 1881 he accepted a challenge to stage a public demonstration of his methods of immunizing cattle against anthrax. The demonstration, carried out before a large gathering of distinguished men, was wholly successful and did much to establish general acceptance of his views. It is impossible to compute the number of lives that have been saved by the general introduction of the principles of vaccination into medicine.

Not until 1887, however, was the controversy which had raged about Pasteur's work completely stilled. In the previous year the British Government had appointed a commission—which included James Paget, Joseph Lister, and Henry Roscoe—to study Pasteur's method for the treatment of rabies. In July 1887 they published a report substantiating every claim that Pasteur had made. A few days later he deposited a copy of the report at the offices of the *Académie des Sciences* in Paris. Of this event he said: 'During the long course of my scientific career I have never experienced a happiness equal to that which I felt on reading this report.'

Pasteur's work is notable for the breadth of understanding which he displayed in the study of widely differing phenomena. Any one of his great discoveries—in stereochemistry, in fermentation, or in bacteriology—would have assured him undying fame. Yet the validity of some of his work was questioned in France, and he was faced at times with violent opposition. That one man should have made so many brilliant discoveries, and despite bitter criticism, is truly amazing. His success, as already remarked, may be attributed in part to his pioneer use of chemical methods in the study of biological problems. He was entering an almost untouched field, and with so powerful a tool was able to reap a great and immediate harvest. His successors in the field of biological chemistry have made equally great discoveries, but few individual efforts have been comparable with his. 'Let us all work,' wrote Pasteur; 'that only is enjoyable.'

In 1887 subscriptions were invited for the building of a research institute in which Pasteur could worthily continue his work. There was an immediate response from all over the world, and on 14th November, 1888, the Pasteur Institute was opened in Paris. Today this building and other Pasteur Institutes in many different parts of the world form a fitting memorial to him and his achievements.

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The age of the earth

ARTHUR HOLMES

The history of the many efforts that have been made to discover the age of the earth's crust reveals a remarkable alternation of contrasted estimates—long and short. Kelvin applied a corrective by insisting that the time that has elapsed since the earth consolidated sets an upper limit to the duration of geological history. Professor Holmes here describes the latest refinement in methods based upon the detailed study of radioactive minerals, and concludes that from the data at present available the most probable estimate is 3,350 million years.

Long before it became a scientific aspiration to estimate the age of the earth's crust, many elaborate systems of world chronology had been devised by the sages of antiquity. The most remarkable of these occult time-scales is that of the ancient Hindus, who calculated that it is now (A.D. 1947) 1,972,949,048 years since the earth came into existence. By a curious coincidence this characteristically precise assessment is of the same order as the 2,000 million years which has recently been the most widely favoured estimate for the age of the expanding universe.

If geological concepts had developed in a community endowed in advance with so generous a concept of the past, much confusion and bitter controversy might have been avoided. But in western Europe the age of the earth had long been identified—to within a few days—with the few thousand years of mankind's history as recorded in the narratives of the Old Testament. On the interpretation of Archbishop Ussher (1581–1656), the creation of the world took place in the year 4004 B.C., and pioneer geologists whose observations suggested that the Mosaic traditions might not be scientifically reliable were branded as dangerous heretics.

A mild though significant instance of the prejudicial influence of this cramping limitation of time is afforded by a remark made by the renowned astronomer Edmund Halley (1656–1742) in the course of a communication to the Royal Society on a *Proposal . . . to discover the Age of the World* (1715). Halley realized that the sea had become salt because of the accumulation of saline material contributed by inflowing rivers, and he suggested that the total amount of salt in the sea might therefore provide a measure of the age of the oceans. At that time the necessary data for making the calculation were not available, and Halley lamented that the ancient Greek and Latin authors had not 'delivered down to us the degree of the saltness of the sea, as it was about 2,000 years ago; for then,' he continued, 'it can not be doubted but that the difference between what is now found and what was then, would become very sensible.' Now obviously, if Halley had been thinking in millions of years instead of thousands, he must have realized that the increase of salinity since Greek or Roman times would be quite undetectable. Nevertheless, he did not fail to express his suspicion that 'the world may be found much older than many have hitherto imagined.' It was James Hutton (1726–97) (see page 109) who first clearly grasped the full significance and immensity of geological time.

Today we know that the earth's history has included a succession of at least ten major cycles, each involving (1) thick accumulations of sediments and volcanic rocks in a subsiding belt of the crust; (2) intense compression of the belt, resulting in folding and crumpling, and accompanied by metamorphism of the deeper rocks and the formation of great masses of granite; and (3) general uplift of the belt and the wearing away of its exposed portions by denudation. The effects of such changes are illustrated in figures 1 and 2. The Alps and the Himalayas are examples of mountain systems now in stage (3) of the latest of these mountain-building or 'orogenic' cycles, as they are called. The rocks of Cornwall and Devon are relics of the immediately preceding cycle, and those of the Lake District and most of Scotland and Wales and Norway belong to the next earlier one. From beneath the North-West Highlands of Scotland and the mountains of Scandinavia the rocks of even older cycles appear (figure 3). So, going farther afield than Hutton did, we can travel back through a long series of these contorted records of earth history. But however far we penetrate into the past we still, like Hutton, find 'no vestige of a beginning.' How this comes about can readily be grasped by reference to figure 6 (page 104). In every continent the oldest known rocks are

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found to be metamorphosed sedimentary types which gradually merge into completely reorganized rocks such as granite. The granite, however, instead of being older than the rocks in which it is emplaced, is actually younger, since it crystallized in its present form during or after the folding of the pile of sediments with which it is associated. Everywhere the oldest visible rocks pass sideways or downwards into granitic foundations that are younger than themselves. But since the oldest visible rocks are of sedimentary origin, they must have been derived from rocks of still greater age: from rocks now represented by pebbles and sand grains, and of which no other recognizable trace has so far been found.

Hutton's experience covered only a small proportion of the earth's history now known to us, and he was therefore recording no more than the sober truth when he declared he could find 'no vestige of a beginning.' In the absence of guiding data, he made no attempt to estimate the rates of geological processes or the periods represented by their products. Many of his successors, however, exhilarated by their newly-found freedom, became unduly reckless in their extravagant demands for time. In 1859, for example, Darwin estimated from the supposed rate of chalk erosion in Kent that the time required for the denudation of the Weald and the recession of the bordering escarpments of the North and South Downs to their present positions was probably about 300 million years. We now know that this estimate was at least five times too long; but Jukes, commenting on it at the time, thought it quite as likely that the period required might have been a hundred times as long. Evidently 30,000 million years was not considered absurdly excessive for a small fraction of geological time.

Kelvin, one of the greatest pioneers of geophysics, then entered the field with a dramatic counterblast against the current assumptions of unlimited time. He argued that since there is a heat-flow through the earth's crust, measurable in terms of the downward increase of temperature and the thermal conductivities of rocks, the earth could be regarded as a cooling globe which must therefore have been progressively hotter in the past. Beyond the dim horizon of the oldest rocks he envisaged a 'beginning' corresponding to the time when the earth was molten and newly born from the sun. In 1862 he set himself the problem of calculating the time that had elapsed since the earth's consolidation. Because of uncertainty in many of the data, he allowed wide limits to his solution, concluding that the observed temperature gradients would have been notably lower than they are if the crust had solidified more than 400 million years ago, and notably higher than if solidification had been completed less than 20 million years ago.

Kelvin's challenge initiated one of the many scientific controversies that enlivened Victorian times. Despite many protests, however, he finally narrowed his limits to 20 and 40 million years (1897). Archibald Geikie pointed out in 1899 that the testimony of the rocks clearly denied Kelvin's thermodynamic inference that geological activities must have been more vigorous in the past than they are today, and that the known sequence of sedimentary strata could not have accumulated within the limits set by Kelvin's solution of the problem. Moreover, James Geikie (1900) showed very convincingly that the crustal compression set up by even 100 million years of cooling would be confined to an outer shell far too thin to accommodate the immense thicknesses of folded rocks involved in the Alps and other great mountain ranges. Evidently some factor—if not more than one—had been overlooked, though few physicists were then willing to admit the possibility of any fundamental mistake. Perry, however, had already heartened the geologists by pointing out that it was allowable to assume a relatively high thermal conductivity for the deep interior of the globe, in which case the cooling of the crust would have been correspondingly slowed down. He saw no reason for denying the geologists anything up to 4,000 million years, an estimate of an order that has been confirmed by Wasiutynski in the course of a recent discussion of the earth's thermal history (1946).

Nevertheless, Kelvin's great authority compelled a compromise, and at the turn of the century geologists who claimed more than about 100 million years were thought to be unduly rash. A few, indeed, reluctantly satisfied themselves with a more meagre allowance of time, but the majority steadfastly refused to accept Kelvin's results as final. The real flaw in Kelvin's assumptions was disclosed shortly after the discovery of radioactivity, when Strutt (Lord Rayleigh) detected the presence of radium in common rocks from all parts of the world. With the demonstration that the crustal rocks contain radioactive elements and are therefore endowed with an unfailing source of heat, it became obvious that the earth is not living merely on its ancestral capital of internal heat, as Kelvin had confidently believed, but that it has an independent and regular source of income

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TRE 1 (*above*) – *Upper Old Red Sandstone strata (age* 280 *million years) resting unconformably on vertical* ian *rocks (about* 320 *million years) at Siccar Point, Cock-*path, *Berwickshire.*

(*Photograph by H.M. Geological Survey, Crown copyright reserved*)

FIGURE 2 (*below*) – *Carboniferous Limestone (about* 240 *million years) resting unconformably on inclined Silurian slates (about* 320 *million years) at Arco Wood Quarry, four miles north of Settle, Yorkshire.* (*Photograph by Professor S. H. Reynolds*)

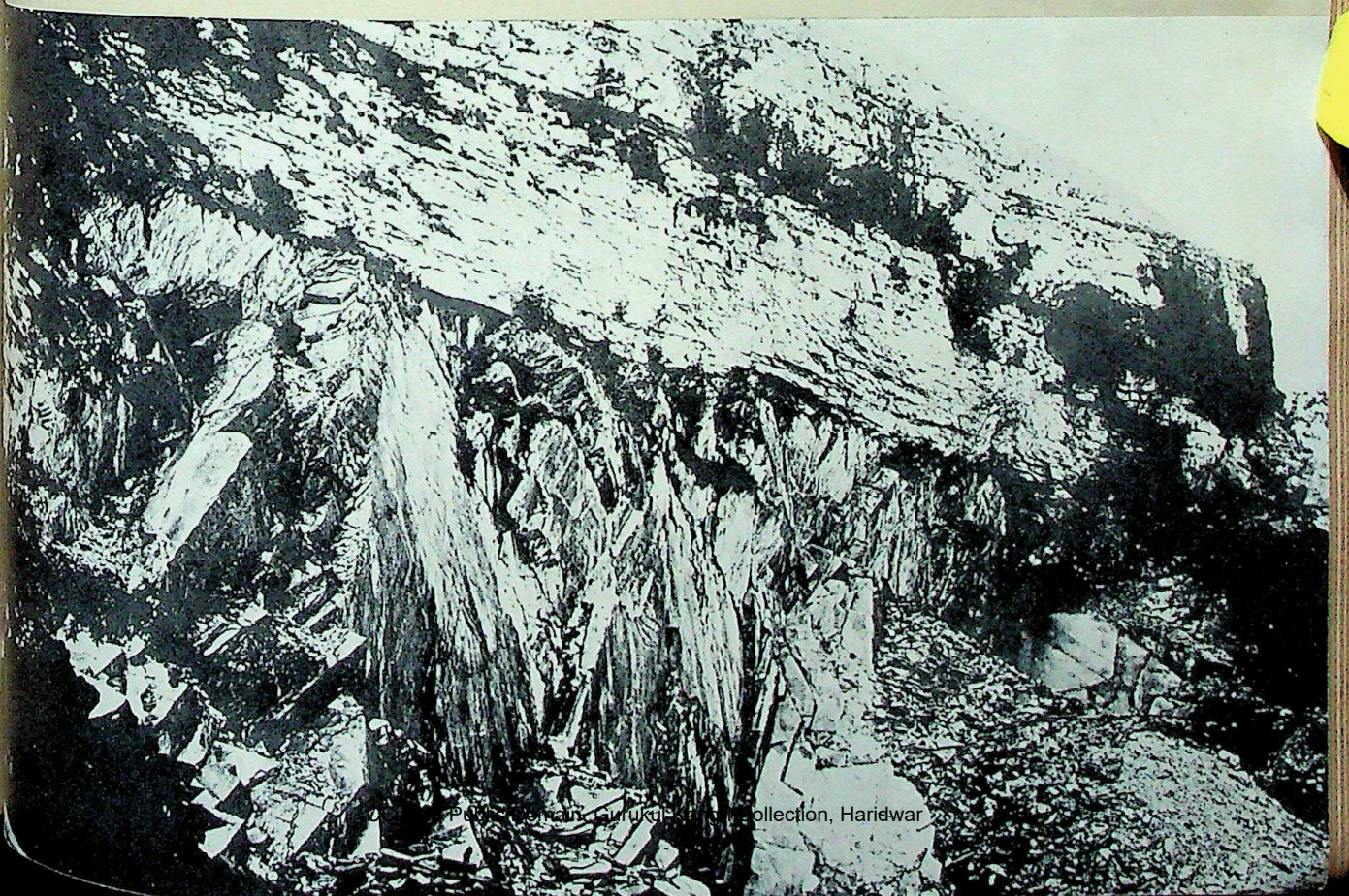

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FIGURE 3 – *Wave-swept surface of folded rocks, metamorphosed and partly granitized, representing the worn-down roots of a Pre-Cambrian orogenic belt (about 1,050–1,100 million years), at Borgâ, south coast of Finland.*

(Photograph by Professor C. E. Wegmann)

FIGURE 4 – *Pleochroic halo in mica from Murray Bay, Quebec, showing well-developed rings due to α-particles shot out from a uranium-bearing crystal at the centre.*

(Photomicrograph by Professor G. H. Henderson)

FIGURE 5 – *Pleochroic haloes in a flake of brown mica from a Pre-Cambrian granite (about 1,030 million years) from Ontario, Canada.*

(Photomicrograph by Professor G. H. Henderson)

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of its own. The abundance of the radioactive elements in the crustal rocks is such that the net loss of heat is extremely low; age estimates based on the rate of cooling are therefore greatly increased. If, for example, nine-tenths of the heat-flow through the crustal rocks is of radioactive origin—and something of this order is consistent with the available evidence—then the alleged 20–40 million years of cooling has to be multiplied by 100 or more.

By this time the minds of the older geologists were no longer attuned to thinking in terms of thousands of millions of years, and few of them were prepared to take advantage of the new discoveries. This reluctance was largely due to the fact that in 1898 Joly had resuscitated Halley's suggestion for determining the age of the oceans. Adopting the simple hypothesis that—on an average—the annual amount of dissolved sodium removed by rivers from the land has remained constant throughout geological time, he found that about 80–90 million years would be required to furnish the total amount of sodium now present in the oceans. This estimate he shortly afterwards increased to 100 million years. A few years later Sollas concluded that the probable limits were 80–150 million years. In 1910 Becker, thinking it likely that the annual increments had been progressively greater in the past, reduced the probable age to about 60 or 65 million years. Indeed, Becker was sufficiently convinced of the validity of these 'short' estimates to declare that 'radioactive minerals cannot have the great ages which have been attributed to them.'

It is therefore of some importance to consider the present status of the sodium method. It appears from recent discussion of the relevant geochemical statistics (see especially Conway, 1942 and 1943) that practically all the 'chloridized' sodium in river water represents oceanic salt, either blown inland and washed down by rain, or derived from saline deposits or the pore-spaces of sediments. Allowing for such 'second-hand' salt, the present annual addition of new sodium is about 6×10^7 tons. Even this figure may be misleadingly high, because, as Lane has pointed out, analyses are rarely made of the water from rivers when they are in flood, i.e. when the content of dissolved material is at its minimum. The total accumulation of marine sodium in ocean water and sediments is estimated at about 15×10^{15} tons, less the amount initially present, which may or may not be negligible. Thus, on the assumption of past uniformity, all we can conclude is that the apparent age of the oceans is something of the order of 250 million years. But past uniformity can by no means be assumed. Present rates of weathering and erosion are far too abnormally high to be representative of the geological past. Mountain ranges and land areas in general are now much more elevated and extensive than has usually been the case. Rivers and ground waters are therefore unusually active, and, moreover, many of them drain regions that are thickly strewn with easily weathered glacial deposits. Finally, human activities of all kinds—agricultural, engineering, and chemical—have still further speeded up the rates of weathering and erosion over widespread areas.

Only a crude attempt can be made to assess the effects of these considerations on the 'apparent' age of the oceans. Figure 6 illustrates the observed fact that the continents are made up of belts of rocks that have suffered intense compression, folding, and thickening. If we imagine—going backwards in time—all the folds to be straightened out, then the crustal layer responsible for the continents becomes increasingly attenuated and extensive; so much so that in the early days of geological history this continental layer would be spread out so thin that its surface would be below sea level, and the only lands would be a few volcanic islands. Since then the continental lands exposed to erosion have, on the whole and despite wide fluctuations, progressively increased in height and area. According to this conception, the quantitative effects of denudation must have gradually increased from almost zero at the beginning to the all-time maximum of the present epoch. Roughly we may reckon that the time-average rate was probably between $\frac{1}{2}$ and $\frac{1}{3}$ of the present rate in respect (separately) of area, height, and relief. That is, it was probably between $(\frac{1}{2})^3$ and $(\frac{1}{3})^3$ of the present rate. The age of the oceans may therefore be anything between 8 and 27 times the apparent age of 250 million years, which itself may be a minimum. Obviously the hour-glass of sodium accumulation is a hopelessly variable timekeeper. The most that can be said is that its present reading is not inconsistent with an oceanic age of a few thousands of millions of years.

What we need for the accurate measurement of such immense periods is a natural process that has operated throughout geological time and has produced measurable results at a known rate, of which the law of variation with time is also known. The decay of the radioactive elements is the only known process that fulfils these stringent conditions. The radioactive methods depend on the

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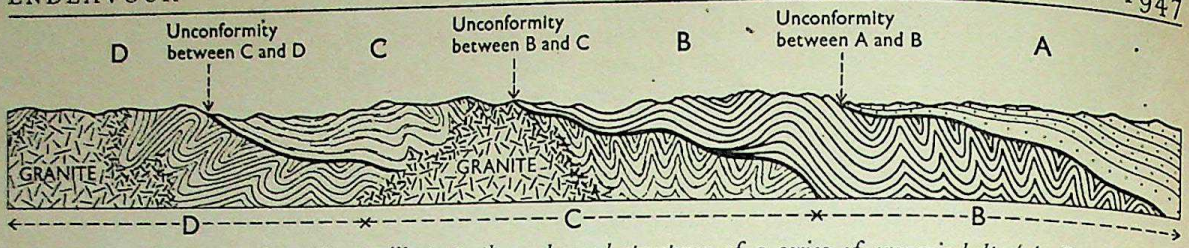

FIGURE 6 – *Diagrammatic section to illustrate the rocks and structures of a series of orogenic belts (A, B, C, and D) such as make up the continental crust of the earth. (Vertical scale greatly exaggerated.)*

transformation of uranium and thorium into helium and lead, and on the accumulation of these stable end-products in minerals and rocks that contain the parental elements. Helium, being a gas, is liable to escape, but the lead is much more likely to be retained and so to serve as an index of age. Provided a radioactive mineral such as pitchblende or uraninite has remained unaltered by weathering or other changes, then the amount of radiogenic lead now found within it is a function of (*a*) the amounts of uranium and/or thorium now present and (*b*) of the time elapsed since the mineral first crystallized. Fortunately it is possible to discriminate between the radiogenic lead and any ordinary lead that may have been present as an initial impurity in the mineral. The parental uranium contains two chemically inseparable isotopes, U_I (or U^{238}) and AcU (or U^{235}), in atomic proportions having the present value $AcU/U_I = 1/139$. Since AcU decays much more rapidly than U_I, this ratio was progressively higher in the past. The material results of the atomic transformations can be summarized as follows:

$$U^{238} \rightarrow Pb^{206} + 8He$$
$$U^{235} \rightarrow Pb^{207} + 7He$$
$$Th^{232} \rightarrow Pb^{208} + 6He$$

It will be noticed that in each case a specific isotope of lead is generated. Ordinary lead is a mixture of the same three isotopes, together with a fourth, Pb^{204}, which is not known to be an end-product of radioactive decay. Thus, if the lead separated from a radioactive mineral is isotopically analysed (e.g. by means of the mass-spectrograph) and found to contain Pb^{204}, the proportion of the latter provides an index of the amount of ordinary lead that was initially present.

The present rates of production of radiogenic lead are known with a remarkable degree of accuracy, but the question naturally arises: can we be reasonably sure—apart, of course, from the inevitable slowing down due to the wearing out of the parents—that these rates have remained constant throughout geological time? In other words, can we be sure that the physical constants concerned have not varied with time? Fortunately, pleochroic haloes provide us with an unambiguous affirmative. Certain granites contain flakes of brown mica which, under the microscope, can be seen to be sprinkled with dark circular spots (figure 5, page 102). These are known as pleochroic haloes, and some of them, when highly magnified, reveal a beautifully developed pattern of concentric rings (figure 4, page 102). A minute radioactive crystal lies at the centre of each halo, and the darkening of the surrounding mica is produced by the helium atoms (α-particles) that are shot out in all directions. The radius of each ring corresponds to the range of the α-particles from one particular radioactive element. Careful measurements by G. H. Henderson (1943) show that the rings in Pre-Cambrian haloes over 1,000 million years old are just as sharply defined as those in younger rocks, and that the corresponding radii and ranges are identical. Since the range, in turn, depends on the rate of disintegration of the radioactive element concerned, it follows that the radioactive constants have not varied appreciably for at least 1,000 million years.

At any given time the rate of production of a particular lead isotope depends only on the disintegration constant and amount of the parental element then present. Thus the age of a mineral t_m can be readily calculated from each of the three ratios Pb^{206}/U, Pb^{207}/U, and Pb^{208}/Th, where these symbols here represent the percentages of the parent elements and of the isotopes of radiogenic lead now present in the mineral under investigation. The respective equations for t_m are (Keevil, 1939):

$$t_m = 15{\cdot}15 \times 10^9 \log_{10} (1 + 1{\cdot}158\ Pb^{206}/U) \text{ years}$$
$$t_m = 2{\cdot}37 \times 10^9 \log_{10} (1 + 159{\cdot}6\ Pb^{207}/U) \text{ years}$$
$$t_m = 46{\cdot}20 \times 10^9 \log_{10} (1 + 1{\cdot}116\ Pb^{208}/Th) \text{ years}$$

A fourth value for t_m can be found from the ratio Pb^{207}/Pb^{206}.

If a mineral has remained unaltered, then all

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four values for t_m should be in close agreement. In practice this rarely happens, because, even in the freshest-looking mineral, migrations of the critical elements are likely to have occurred. Fortunately, even if the three values for t_m based on Pb^{206}/U, Pb^{207}/U, and Pb^{208}/Th are widely different the relations between them provide criteria for assessing the true age (figure 7). If there has been leakage of radon (the gaseous member of the U1 family), then the mineral is necessarily deficient in Pb^{206}; in this case the most probable age is given by Pb^{207}/U (see Wickman, 1942, and Holmes [5], 1947*b*). If there has been loss of Pb or U or both, or gain of either or both, then the true age, or a close approximation to it, is given by Pb^{207}/Pb^{206}.

Although a great many radioactive minerals have been chemically analysed, relatively few isotopic analyses of the lead have been made as yet. Professor A. O. Nier, following up Aston's pioneer work, has been the most active and successful worker in this field. As an example of a fully investigated mineral, samarskite from Spinelli Quarry, Portland, Connecticut, may be taken. The mineral occurs in a pegmatite dating from about the end of the Devonian period.

	Pb	*U*	*Th*	*'Apparent Age' from total Pb (million years)*
Percentages (R. C. Wells)	0·314	6·91	3·05	295

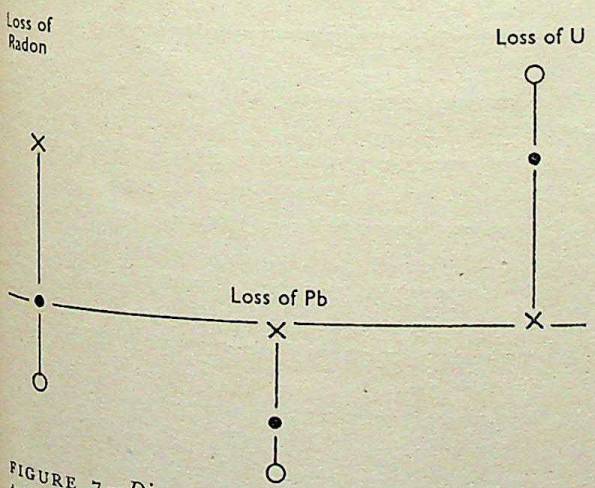

FIGURE 7 – *Diagram to illustrate the effects of various types of alteration on the apparent ages of a radioactive mineral calculated from Pb^{206}/U (open circles); Pb^{207}/U (solid circles); and Pb^{207}/Pb^{206} (crosses). The horizontal line represents the true age of the mineral, points above and below being respectively too high and too low.*

Isotopic Proportions (Nier *et aliter*)	Pb^{204}	Pb^{206}	Pb^{207}	Pb^{208}
In total lead ..	0·167	100·00	7·60	21·30
In original lead	0·167	3·04	2·61	6·35
In radiogenic lead	—	96·96	4·99	14·95
Percentages ..	—	0·236	0·012	0·036
Age Ratios	$\frac{Pb^{207}}{Pb^{206}}$	$\frac{Pb^{206}}{U}$	$\frac{Pb^{207}}{U}$	$\frac{Pb^{208}}{Th}$
	0·0515	0·03415	0·00174	0·0118
Values of t_m (million years)	256	255	254	266

Here the agreement is unusually good, and it can be concluded that about 255 million years have elapsed since the close of the Devonian period.

In the following table some of the better-established dates are listed:

Mineral	*Locality*	*Geological Age*	*Probable Age (millions of years)*
Pitchblende	Colorado	Beginning of Tertiary	58
Pitchblende	Bohemia	Late Carboniferous	215
Samarskite	Connecticut	End of Devonian	255
Cyrtolite	New York	End of Ordovician	350
Kolm	Sweden	Upper Cambrian	440
Pitchblende	Katanga, Belgian Congo	Pre-Cambrian	580
Uraninite	Morogoro, Tanganyika	Pre-Cambrian	590
Uraninite	Besner, Ontario	Pre-Cambrian	760
Bröggerite	Moss, S. Norway	Pre-Cambrian	860
Uraninite	Wilberforce, Ontario	Pre-Cambrian	1,035
Cleveite	Aust Agder, S. Norway	Pre-Cambrian	1,075
Pitchblende	Great Bear Lake, Canada	Pre-Cambrian	1,330
Uraninite	N.E. Karelia, U.S.S.R.	Pre-Cambrian	1,765
Uraninite	Huron Claim, Manitoba	Pre-Cambrian	1,985

The uraninite from Manitoba is the oldest mineral so far investigated, and its great age is roughly confirmed by analyses of another uraninite and of two monazites, all from the same pegmatite. The 'apparent ages' of these, calculated from the total lead, are 1,950, 1,955, and 1,990 million years respectively. The pegmatite represents the closing phase of the plutonic activity of a typically Archaean orogenic belt. It followed a long series of granitic and other plutonic rocks, which in turn are emplaced within a thick sequence of metamorphosed volcanic and sedimentary rocks. The

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latter include still recognizable conglomerates, containing pebbles of pre-existing granites and quartzites, which must therefore be well over 2,000 million years old. Since the earth must be older still, this figure can be regarded as a conservative minimum for its age.

To find a maximum for the age of the earth we may assume that when the earth began it was free from the lead isotope Pb^{207}, and that all the Pb^{207} now present in the common granitic rocks of the continental crust has since been generated from U^{235}. Granitic rocks contain on an average about 20 parts per million of lead and 3·5 parts per million of U. The isotopic constitution of granitic lead has not yet been determined directly, but isotopic analyses of several samples of lead from galena and other lead ores of Tertiary age have been made by Nier and his co-workers. These ores represent concentrations of the granitic lead of some 25 million years ago, which is near enough to the present for our purpose. The average isotopic abundances of Tertiary lead are:

Pb^{204}	Pb^{206}	Pb^{207}	Pb^{208}	*Total (parts per million)*
1	18·54	15·55	38·28	73·37

corresponding in parts per million very nearly to

0·27	5·1	4·2	10·4	20

in the average granitic rocks of today. Inserting the value $Pb^{207}/U = 4·2/3·5$ in the appropriate formula given on page 104, the time required for the generation of all the Pb^{207} is found to be 5,400 million years. The age of the earth is therefore somewhere between 2,000 and 5,400 million years.

Can we arrive at a closer estimate? I think we can, again by making use of the invaluable data provided by Nier (see Holmes, 1946). Nier and his co-workers have determined the relative abundances of the isotopes in twenty-five samples of lead from common lead minerals of various geological ages. The results, graphically summarized in figure 8, reveal internal relationships between Pb^{206}, Pb^{207}, and Pb^{208} that are almost exactly what they would be if the primeval lead originally present in the material of the outer earth had been slowly modified by additions of radiogenic lead. A few of the samples have a more or less abnormal constitution, but, apart from these, the evidence is clear that ore-lead represents a concentration of the lead that was dispersed through the crustal rocks of the region concerned at the time when the ore deposition took place.

The problem, then, is this: knowing the isotopic constitution of rock-lead as it was at various periods ranging from 1,330 million years ago (the Great Bear Lake sample) to 25 million years ago (the Tertiary samples), to find the relative abundances of Pb^{206} and Pb^{207} in the earth's primeval lead and the time that has elapsed since that primeval lead began to be modified by radiogenic additions. This time (t_o) is the required age of the earth.

Using the following symbols, with t_m for the age of the lead ore:

	Pb^{204}	Pb^{206}	Pb^{207}	Pb^{208}
Ore-lead (≡ rock-lead) ..	1	a	b	c
Primeval lead	1	x	y	z
Radiogenic lead (from t_o to t_m)	—	$a-x$	$b-y$	$c-z$

we can write:

$$\frac{b-y}{a-x} = r = \frac{\text{No. of atoms of } Pb^{207} \text{ generated from } t_o \text{ to } t_m}{\text{No. of atoms of } Pb^{206} \text{ generated from } t_o \text{ to } t_m}$$

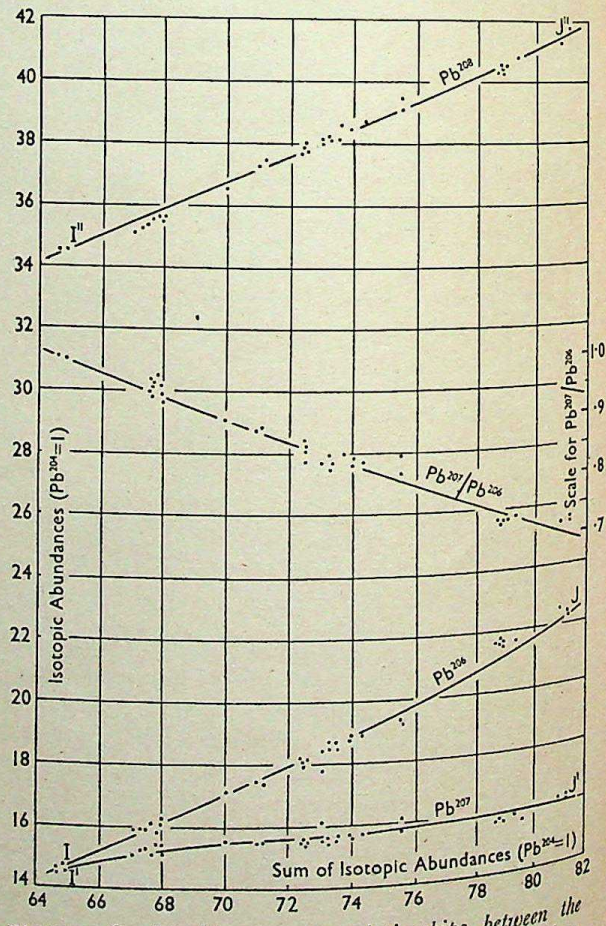

FIGURE 8 – *To illustrate the relationships between the abundances of Pb^{206}, Pb^{207}, and Pb^{208} (relative to Pb^{204} = 1) in lead samples prepared from common ores of lead.*

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From the expression on the right r can be calculated (for each appropriate value of t_m) for various assigned values of t_o from 2,000 to 5,000 million years. For each assigned value of t_o we have:

$$ar - xr = b - y \quad \text{for a lead sample of age } t_m$$

and $$a'r' - xr' = b' - y \quad \text{for a lead sample of age } t_m'$$

whence $$x = \frac{b - b' + a'r' - ar}{r' - r}$$

and $$y = b + rx - ar$$

Taking samples 25 and 18 (figure 10, page 108), the following results are obtained:

No. 25 *Galena, Great Bear Lake (Pre-Cambrian)*	*No.* 18 *Galena, N. Carolina (Late Carboniferous)*
	$a' = 18{\cdot}43$
$a = 15{\cdot}93$	$b' = 15{\cdot}61$
$b = 15{\cdot}30$	$t_m' = 220$ million years
$t_m = 1{,}330$ million years	

When $t = 2{,}500$ million years:

$r = 0{\cdot}23305$ $\quad r' = 0{\cdot}16999$

$x = 14{\cdot}11$ $\quad y = 14{\cdot}87$

When $t = 3{,}000$ million years:

$r = 0{\cdot}30156$ $\quad r' = 0{\cdot}22794$

$x = 12{\cdot}40$ $\quad y = 14{\cdot}24$

When $t = 3{,}500$ million years:

$r = 0{\cdot}39685$ $\quad r' = 0{\cdot}30985$

$x = 10{\cdot}59$ $\quad y = 13{\cdot}18$

Plotting x against t, a curve AB is drawn; a point representing a solution for x and t_o lies somewhere on this curve or its continuation. Dealing in the same way with another pair of lead samples, such as No. 1 (galena, Peru, Tertiary, 25 million years) and No. 19 (galena, Ivigtut, Greenland, Late Pre-Cambrian, 600 million years), a curve CD is similarly constructed. Where the two curves intersect (at P in figure 10) $x = 1{\cdot}22$ and $t_o = 3{,}330$ million years.

In the same way we can plot y against t and construct two curves that intersect at $y = 13{\cdot}71$ and

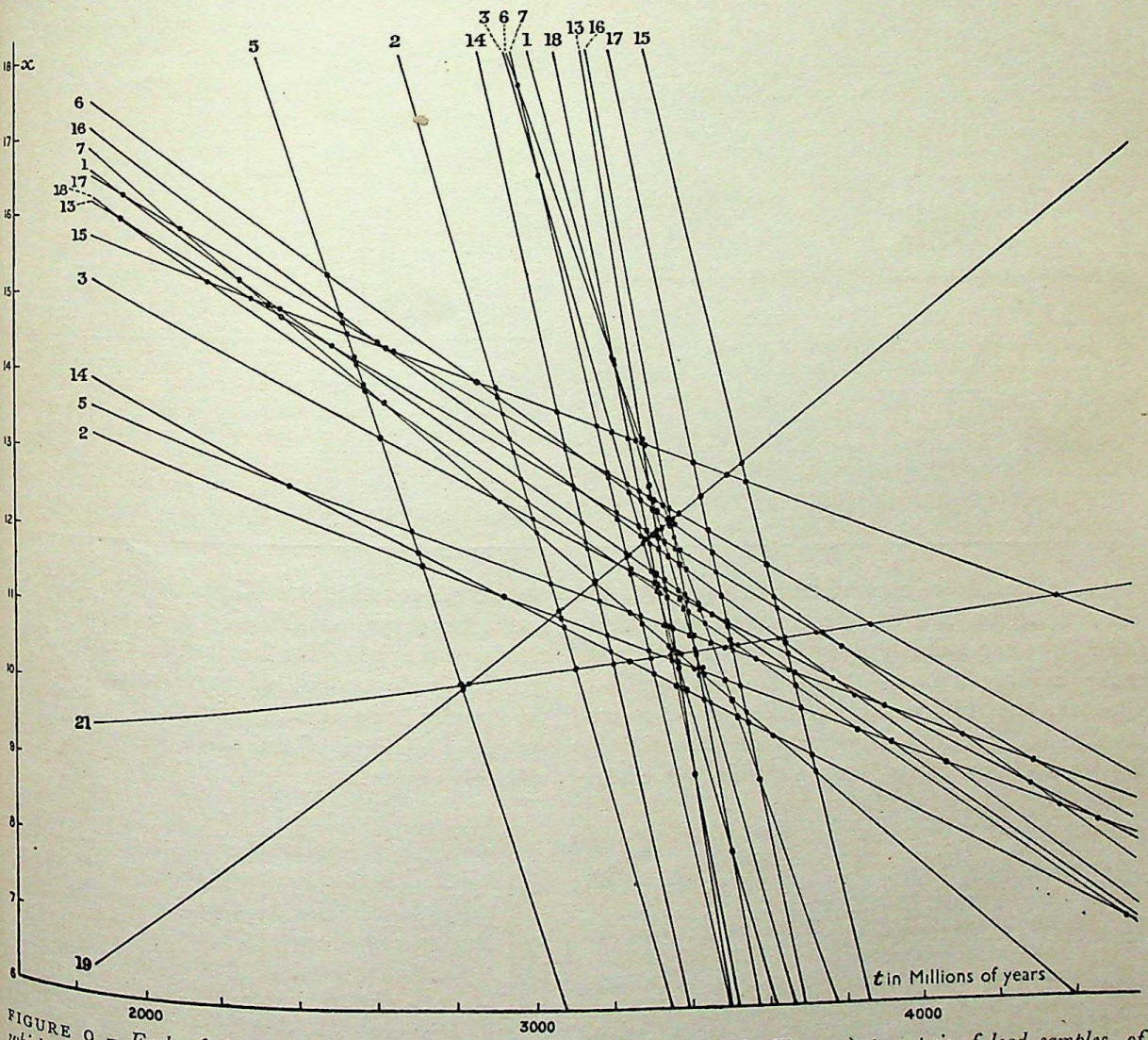

FIGURE 9 – *Each of the curves numbered on the left corresponds (like AB in Figure 9) to a pair of lead samples, of which No. 25 is one. The curves similarly based on No. 19 are numbered along the top. The numbers are those of Nier's lead samples as listed in Holmes* (1946). *Each intersection, marked by a dot, provides a solution for x and* t_o. (*See page* 108.)

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t_o = 3,330 million years. The two pairs of curves, based on the data for two pairs of lead samples, thus yield a solution of the problem.

Obviously a great many solutions can be obtained by this method. Figure 9 illustrates the *xt* curves for pairs made up of No. 25 with each in turn of fourteen younger lead samples, and for pairs made up of No. 19 with 11 younger lead samples. The intersections provide over two hundred solutions, with a marked concentration at about 3,300–3,400 million years.

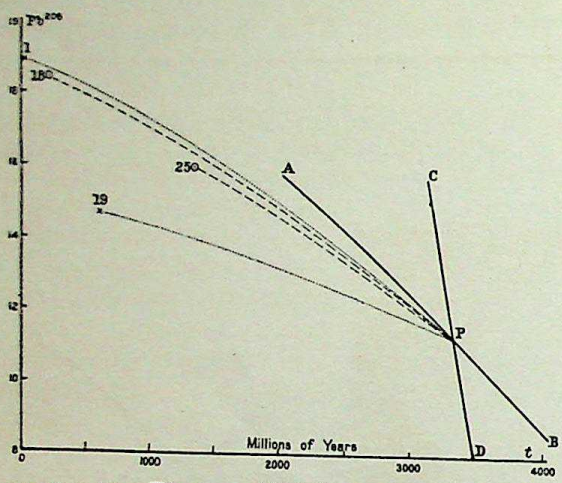

FIGURE 10 – *The curve AB indicates the variation of x (primeval Pb^{206}) with assigned values of t for the pair of lead samples 25 and 18. CD represents the corresponding variation for the pair 19 and 1. The intersection at P gives a solution for x and t_o. The lines joining P to the points representing the lead samples (a and t_m in each case) show the gradual increase of Pb^{206}, relative to Pb^{204} = 1, from x to a during the period t_o–t_m.* (*See page* 107.)

obtained for t_o, *x*, and *y*. The average value of t_o is 3,290 million years, but a histogram of the t_o values (figure 11) reveals a well-marked mode at 3,350 million years, which is found to be somewhat better than the average value when tested by a least-squares method (Holmes [5], 1947*a*). The dotted frequencies on the left of figure 11 illustrate the lopsided effect of including results involving the data for two lead samples of

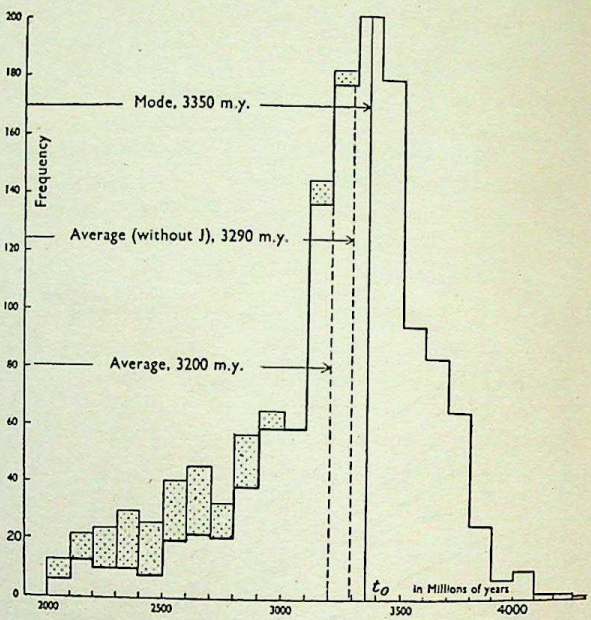

FIGURE 11 – *Histogram representing the frequency distribution of 1,419 solutions for t_o to within ranges of 100 million years. The frequencies of 162 solutions involving the abnormal Joplin lead samples (Nos. 9 and 11) are indicated by the dotted areas. The histogram for the 1,257 solutions without the aberrant Joplin results is outlined boldly.*

Additional sets of curves can be constructed for pairs based on No. 23 (cerussite, Broken Hill, N.S.W., 1,200 million years); No. 22 (galena, same locality and age); and No. 21 (galena, Quebec, 800 million years). From the intersections of all five sets of curves, and those of the corresponding *yt* curves, 1,257 solutions have been abnormal constitution. Certain other abnormal leads, however, would give a concentration of results on the right. The fact that the modal solution remains independent of these aberrant results favours the hope that an estimate of 3,350 million years for the age of the earth is unlikely to be seriously wrong.

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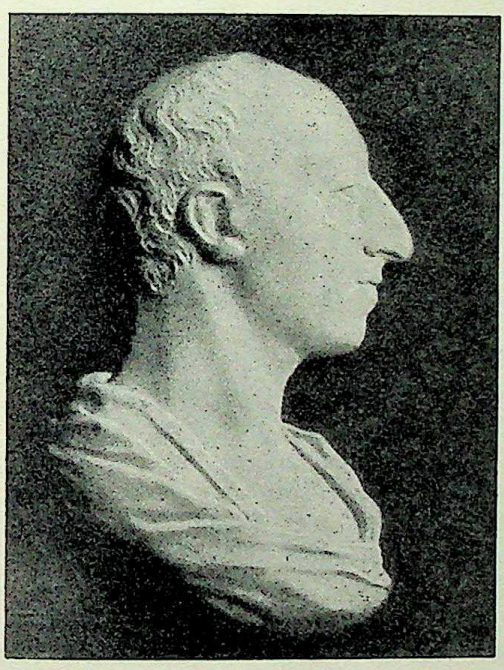
James Hutton, the founder of modern geology: 1726–97

M. MacGREGOR

The second half of the eighteenth century was a period of intense intellectual activity in Scotland. Among the greatest of the many distinguished figures of the time was James Hutton, whose geological researches and writings established the fundamental principles of modern geology. He was the first to recognize and describe the processes which determine the past and present configuration of the earth, drawing his evidence not from the academic speculations in which his contemporaries indulged but from the rocks themselves.

The 26th of March, 1947, saw the hundred and fiftieth anniversary of the death of James Hutton, who has been so often acclaimed as the founder of modern geology. The memory of this great Scotsman is still green, not only in the little northern kingdom where he was born and where he laboured, but throughout the scientific world. To the generality of people he is perhaps best known as the author of the often-quoted saying that in the operations of nature 'we find no vestige of a beginning—no prospect of an end,' words that were startling and indeed iconoclastic when they were written in 1785. At this distance of time it is difficult for us to measure the debt we owe to Hutton's genius or to realize how profoundly the principles he established came to revolutionize the whole trend of scientific speculation. To appreciate the fundamental importance of his work and its far-reaching repercussions, it must be set against the background of the time in which he wrote; and to return to the latter half of the eighteenth century is to enter a new and strange geological world, differing from our own in its concepts and scope. It was a world given over to dogmatisms and preconceived theories, to fantastic explanations invoked to account for natural phenomena, to barren speculations that sought to bring the facts of nature into conformity with the traditional Mosaic chronology. A universal ocean in which the solid rocks now forming most of the dry land had been deposited as chemical precipitates, a succession of sudden, catastrophic events such as the violent, tumultuous upheaval of mountain ranges, and above all, the limitation of the time available for geological changes to a few thousand years, were amongst the commonly accepted tenets of the time. Under these conditions progress in geological research was narrowed and obstructed, and it was Hutton who, by uprooting and sweeping away all such sterile conceptions, placed geology on a solid and secure foundation. To free geology of its accumulated traditions, false analogies, and misconceptions was a Herculean task, but it was a task which he carried out quietly and courageously. To study and understand the processes at work on the surface of the earth, to frame a system of philosophy which would explain them, and to show from the records of the solid rocks themselves that the same processes have operated throughout immeasurable time—this was the work to which he devoted long years of patient observation and reflection. His *Theory of the Earth* is unquestionably one of the great classics of science, by virtue of its wide sweep, its originality, and its irresistible logic. There were no assumptions, no unverified propositions in his doctrine, no principles allowed that were not first submitted to the test of observation. He uses the word 'observable'



Reproduction of medallion portrait of James Hutton, M.D.

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in the sub-title of his famous memoir of 1785, describing it as 'An Investigation of the Laws observable in the Composition, Dissolution, and Restoration, of Land upon the Globe.' Nature herself was to him the ultimate court of appeal. In one memorable passage he wrote: 'It is only in knowing the succession of things, that natural appearances can be explained; and it is only from the examination of those appearances, that any certain knowledge of this operation is to be obtained. But how shall we acquire the knowledge of a system calculated for millions, not of years only, nor of the ages of man, but of the races of men and the successions of empires? There is no question here with regard to the memory of man, or any human record, which continues the memory of man from age to age; we must read the transactions of time past, in the present state of natural bodies; and, for the reading of this character, we have nothing but the laws of nature, established in the science of man by his inductive reasoning.'

HUTTON'S LIFE AND TIMES

Hutton's life-story can be simply told. He was born at Edinburgh on 3rd June, 1726, the son of a merchant who had for a time held the office of City Treasurer. He studied medicine for three years at Edinburgh University and for two years in Paris before taking his doctor's degree at Leyden in 1749. On his return home he decided to abandon medicine for farming, and with this end in view spent two years (1752–4) in Norfolk learning agricultural methods. These years in Norfolk were important and formative ones, because it was at this period that his early passion for scientific research turned definitely in the direction of geology. In 1754 he settled down in Berwickshire, where he devoted himself to the cultivation and improvement of the little estate which had been bequeathed to him by his father. He continued his geological investigations, however, making many excursions to different parts of the country and amassing a wealth of observations and records which he was later to put to such splendid use. About the year 1768 he determined to let his estate and to retire to Edinburgh, and it was in Edinburgh that the last twenty-nine years of his life were passed. It was retirement but in no sense leisure, for Hutton was a man of unwearied industry. He had many interests—philosophy, chemistry (he was partner in a firm manufacturing ammonium chloride), meteorology, and agriculture. He published volumes on physics and metaphysics, including a three-volume treatise entitled *An Investigation of the Principles of Knowledge, and of the Progress of Reason from Sense to Science and Philosophy*. He made a number of important meteorological studies, and he left behind him in manuscript a lengthy treatise on agriculture (now in the possession of the Geological Society of Edinburgh). But his main passion and his main life-work lay in the study of the rocks, minerals, and soils of his native land.

In Edinburgh he had a number of intimate and scholarly friends who took a keen interest in his work, and with whom he could discuss the new ideas which filled his mind: Joseph Black (1726–99), the distinguished chemist, who has sometimes been termed the father of modern chemistry just as Hutton himself has been called the father of modern geology; John Clerk of Eldon, 'that country gentleman who, with pieces of cork on his own dining table, invented modern naval warfare'; John Playfair (1748–1819), who was in later years to write a biographical account of his friend and to produce that inspiring and lucid masterpiece *Illustrations of the Huttonian Theory of the Earth* (1802); and Sir James Hall of Dunglass (1762–1831), who has recorded that 'after three years of almost daily warfare with Dr Hutton on the subject of his theory, I began to view his fundamental principles with less and less repugnance,' and who was later to bring powerful experimental support to Hutton's view that crystalline rocks could under certain conditions be produced by the cooling of originally molten material. It was in 1785, some seventeen years after his return to Edinburgh, that Hutton read before the Royal Society of that city his memoir or essay entitled *Theory of the Earth*. This memoir, occupying ninety-six quarto pages, was published in the first volume of the Society's *Transactions*.[1] A violent and unworthy attack on his *Theory* by a Dublin mineralogist in 1793, an attack which not only travestied Hutton's views but accused him of atheism, made him decide to extend and revise his 1785 memoir and to prepare and publish a more elaborate and complete statement of his position. In this task, weakened by illness as he was (he was now 67 years old), he persevered resolutely, and the immortal *Theory of the Earth, with Proofs and Illustrations* appeared in two octavo volumes in 1795. A third and concluding volume was left in manuscript at Hutton's death in 1797. The only four chapters of this volume that are

[1] See 'The Royal Society of Edinburgh,' by Professor J. Kendall (ENDEAVOUR, V, 18, April 1946).

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known to have been preserved were published in 1899 by the Geological Society of London.

THE HUTTONIAN THEORY

Hutton's *Theory of the Earth* was wide-ranging in its scope, and the many unique contributions it made to geological research are without parallel in the history of the science. It was little noticed during his lifetime, and, indeed, the long controversy between the Neptunists, as those who adhered to the doctrine of a universal and gradually subsiding ocean were called, and the Plutonists, as the followers of Hutton were termed, did not die away until the first quarter of the nineteenth century had gone. It may be useful to give here one illustration of the divergence of views between the two schools. Granite, according to the Neptunists, was a rock of aqueous origin, the first to be laid down as a precipitate from the hypothetical universal ocean. Hutton, on the other hand, taught that granite had once been molten and had been intruded among the rocks in which it is found; and he pointed triumphantly to the observations he had made in Glen Tilt to show that granite veins emanating from the parent body entered and penetrated the surrounding rocks. He was beyond doubt the founder of physical and dynamical geology. He was one of the earliest geologists to stress the denuding and erosive power of running water and the part it played in the formation of valleys; he was the first geologist to recognize that denudation and deposition were closely linked aspects of the same natural process; and he was the first to see clearly that a succession of slow and slight effects would lead inevitably, if given a sufficient length of time, to widespread physiographic changes. It was consummate genius that led him to take the next step in the development of his argument. He turned to the solid rocks to find in them evidence that the same processes of change as he saw in the world around him must have operated again and again in the remote past. As he himself phrased it: 'the present is the key to the past.' The scenery of today is but the latest phase in a long-continued and ever-changing succession of landscape panoramas. One land mass is worn down and the waste products provide the materials for a new one, and continent follows continent in the eternal revolution of nature. Such, in outline, was Hutton's theory, and to the process as he envisaged it he could see neither beginning nor end.

He was the first geologist to recognize the importance of unconformities as providing clear proofs of the cycle of destruction and reconstruction, citing the now classic examples in North Arran, in the Jed near Jedburgh, and at Siccar Point on the Berwickshire coast. He realized that there must exist in nature some powerful force or agency which could elevate the solid rocks formed on the sea floor into new lands, and so initiate a fresh cycle of erosion. This force he found in subterranean pressures, due essentially, he believed, to the effect of heat transmitted from the interior of the earth. It was only by the action of powerful upward pressures that, to quote his own words, 'every species of fracture, dislocation, and contortion . . . and every degree of departure from a horizontal to a vertical position' seen in the uplifted strata could be explained. When he speaks of rock masses as having 'undergone a double course of mineral changes and displacement,' adding that 'consequently the effect of subterranean heat or fusion must be more apparent, and the marks of their original formation more and more obliterated,' geologists will recognize the germ of the hypothesis of regional metamorphism.

In the sphere of igneous geology Hutton's researches were of profound significance. He was the first geologist to assert and to demonstrate the essential differences between molten material poured out at the surface (lavas) and molten material solidified at depth and under great pressures. He was the first to recognize the intrusive character of the granites, whinstones, and porphyries which he encountered in his travels, and of the dykes and veins emanating from the deeper-seated eruptive masses. He noted also the disturbances and the displacements they caused during their intrusion, and the metamorphic effects (to use a modern phrase) they produced upon the strata they cut.

As has been already said, Hutton's *Theory* received little attention during his lifetime. But there was no gainsaying its originality, its magnitude, and its grandeur of conception. It contains the first statement of many of the most fundamental principles of modern geology. 'The very obviousness and familiarity of his doctrine at the present time,' wrote Sir Archibald Geikie, 'when it has become the groundwork of modern geology, are apt to blind us to the genius of the man who first conceived it, and worked it into a harmonious and luminous whole.' Other workers had gone some way along the path that Hutton travelled; he alone reached the mountain tops from which he could see, as it were, the past history of the world unroll itself before him.

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The chemistry of glass coloration

L. M. ANGUS-BUTTERWORTH

The making and working of coloured glasses are among the world's most ancient crafts. Although the empirical methods of the early workers produced results of great beauty, the study of the chemical processes involved has proved a fruitful field of research. The present extensive use of coloured glasses in scientific apparatus, signalling lamps, photographic filters, and other equipment demands a standardized product which is obtainable only as a result of knowledge of the chemical reactions involved and careful control of manufacturing processes.

INTRODUCTION

The history of coloured glasses is longer than that of the transparent white variety. For many centuries before clear glass appeared a large number of different coloured forms had been in common use.

Some of the glazed tiles covering the walls of early Egyptian chambers were magnificent examples of colouring, and polychromes as well as single colours were achieved. Pieces have been found of a vase, bearing the name of a king living in 5000 B.C., which was glazed in green inlaid with purple. Some of the most important colouring oxides employed in glassmaking today, including those of copper, manganese, and cobalt, were known to the Egyptians. Transparent glass did not appear in Egypt before about 660 B.C., when bottles and a few other objects were made of it.

From these early beginnings in Egypt the art of coloured glassmaking gradually spread. One of the first uses of coloured glass in England was in cathedral windows.

A common belief is that we do not know today how to reproduce the brilliant colours of the early cathedral windows. This was partly true up to about a hundred years ago, but today the glass technologist certainly knows far more about colours in glass than was ever known before.

A further point in connection with old cathedral glass is that when originally placed in position it was often very crude in colour and dark in shade. It has taken hundreds of years to become mellowed. Atmospheric attack on the outside of church windows has been the chief agent in creating the beautiful effects we know today. Throughout the centuries there has been steady abrasive action through the rain being driven against the glass by the wind, and chemical dissolving action through the slight acid content of much of our rain water, especially in towns. The combination of these two forces has gradually changed thick and comparatively dark glass to glass which in some cases is as thin as tissue paper and which now has light and vivid colours.

Even the impurities in the metals, which the early glassmakers could not control, gave variety to their products. It was of little consequence if the glass they supplied for church windows never had quite the same colour twice. Exciting surprises were possible—not as in the dull modern world, in which glassmaking materials and processes are so carefully and completely controlled that results are (or should be) well ascertained in advance.

It is convenient to consider the agents for the production of each of the common colours in glass in turn.

BLACK

Cobalt and nickel oxides are used together to give opaque black glasses. Nickel glasses are noted by Professor Woldemar Weyl as absorbing nearly the entire visible spectrum with the exception of the extreme red.

A small antique glass bowl of an almost jet-black colour shown to the author on one occasion by the late Sir William Boyd Dawkins had certainly a high concentration of manganese as the principal colouring agent, possibly with the addition of a little cobalt.

BLUE

Cobalt and copper serve as the usual agents for colouring glasses blue. Of the two, cobalt is the more commonly used. It transmits a deep red band in addition to blue. Accordingly, if a cobalt blue is combined with a copper bluish green, the latter absorbs the red and an excellent blue glass is obtained. If, however, the colour required is to be midway between blue and green, as in signal lenses, copper is used in association with a small amount of iron.

Weyl observes that from the viewpoint of glass technology we need only consider cobalt compounds which are derived from the bivalent cobalt ion, as tervalent cobalt is not stable in the

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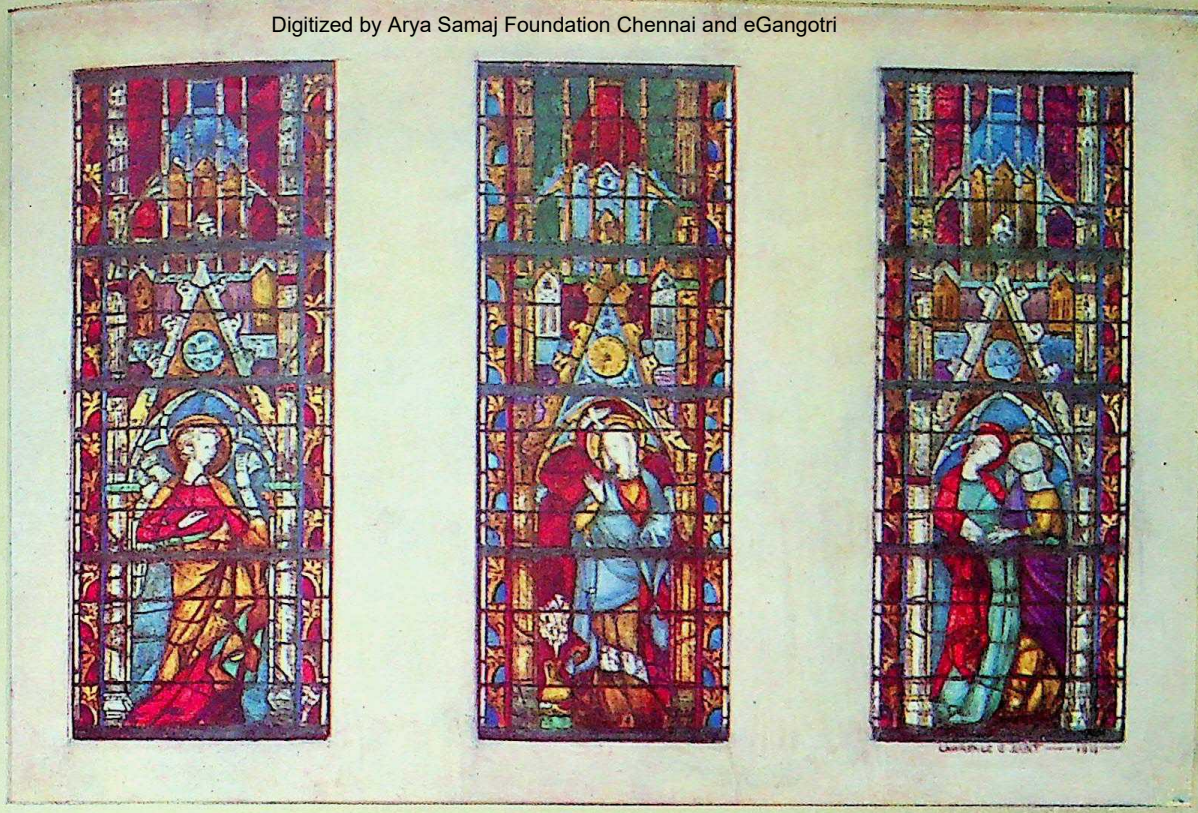

FIGURE 1 (*above*) – '*The Annunciation*,' *from St Ouen, Rouen. Fourteenth century. An example of rich colouring in glass. The prominent yellow is from oxide or chloride of silver.*

FIGURE 2 (*right*) – *Figures of the prophets from the north aisle of the nave, Fairford. Late fifteenth century. The more subdued colouring of a late period window. The red is probably a flashed gold ruby.*

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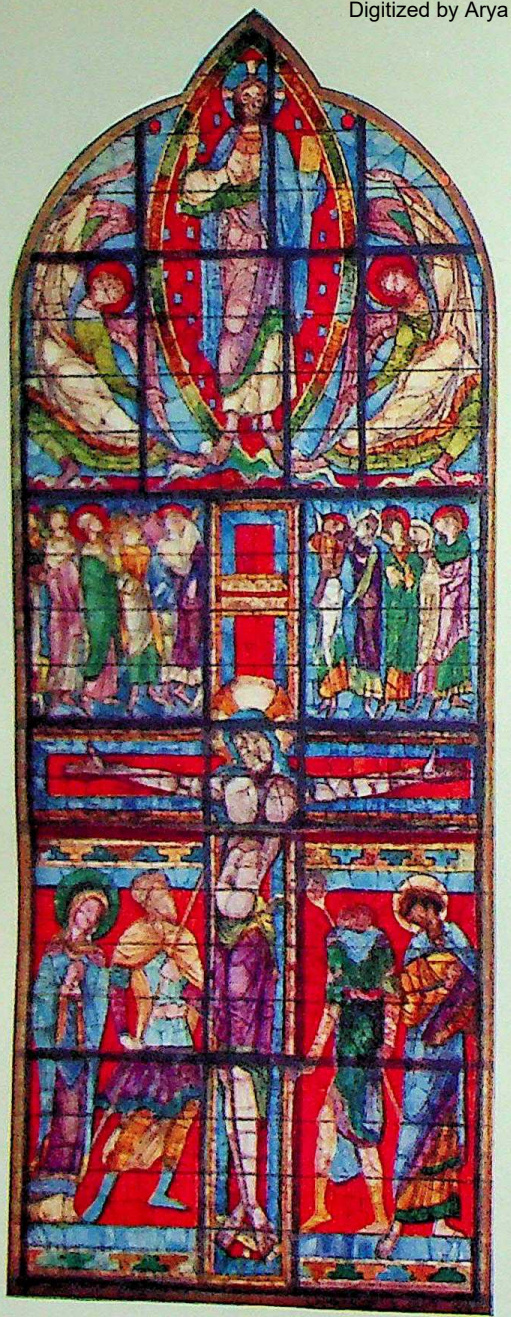

FIGURE 3 (*above*) – *Part of Crucifixion window, Poitiers. Late twelfth century. A brilliant polychrome in glass, showing the command which the glassmaker possessed over his materials even at this early date. Copper and manganese are among the colouring agents used.*

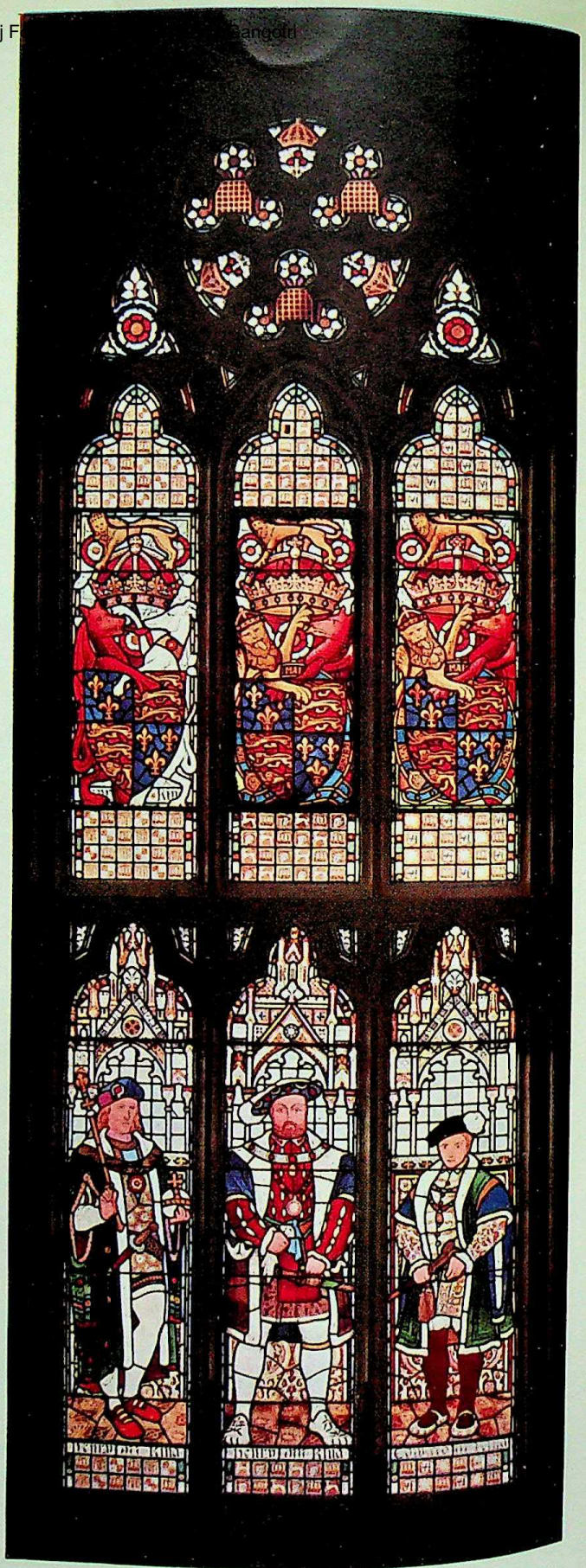

FIGURE 4 (*right*) – *A fine modern example of the use of stained glass for the decoration of a secular building. The red of the Tudor dragons is derived from selenium. The olive-green cloak of Edward VI (right) is from oxide of iron. From the Town Hall, Rochdale.*

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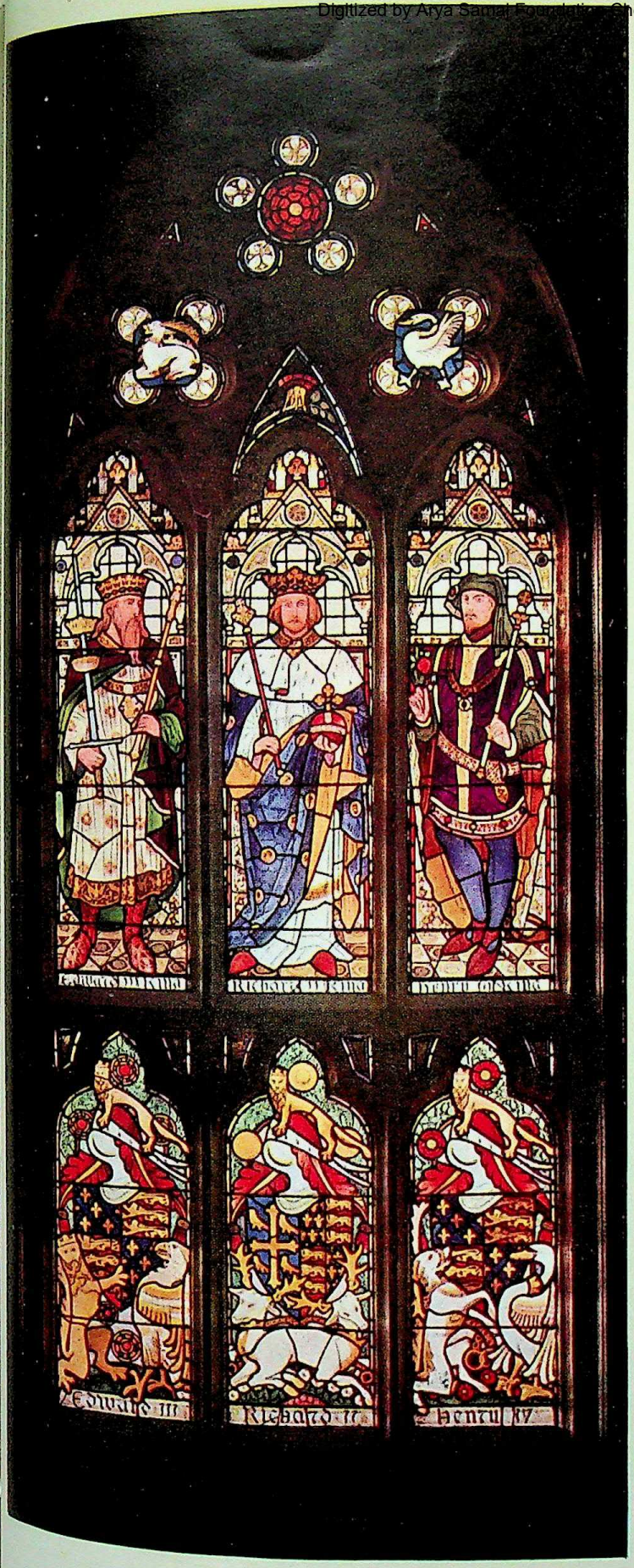

FIGURE 5 (*above*) – *St Luke, from choir clerestory of St Ouen, Rouen. Fourteenth century. The rich ruby red of the mantle is probably from gold chloride. The object of the light grisaille staining is to allow more illumination than is obtainable through the richer but deeper colour of the central figure.*

FIGURE 6 (*left*) – *Colours in glass enable the pomp and circumstance of heraldry to be displayed to special advantage. The colour of the royal robes of Richard II (centre) is from cobalt oxide. From the Town Hall, Rochdale.*

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FIGURE 7 (*top*) – *Bottle decanter. About* 1770–80. *An early form of wine decanter. The vivid blue is derived from copper.*

FIGURE 8 (*below, left*) – *Primitive glass vase, probably from Greek islands. In the attractive decoration of this vase the yellow colour is probably derived from antimony and the blue from copper.*

FIGURE 9 (*below, right*) – *Saracenic enamelled glass. Thirteenth century. This elegant vase is decorated with a blue which is a soda-copper silicate, and an opaque red from oxide of iron, the whole enriched with gold brocading to accentuate the design.*

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temperature range required for glass melting. It has been found that potash glasses give a purer blue than the corresponding sodium glasses, and that borosilicates yield a reddish hue.

An interesting modern use of cobalt is in connection with glassware for lighting. If small amounts of cobalt, manganese, and copper oxides are used together in the batch, what is now known as the daylight effect is obtained. What happens is that these oxides eliminate part of the light from the artificial light sources, and the filtered remainder more closely resembles natural sunlight.

Sir Herbert Jackson suggested that the production and properties of glasses containing copper are representative of those in which the colouring is diffused in very minute particles throughout the glass, and which can be compared with colloidal solutions. In contrast to this, cobalt glasses are examples of those in which the colouring agents are in a state resembling solution, which might be compared to aqueous solutions of coloured salts.

Gmelin noted in 1779 that glasses containing iron became blue when founded under strongly reducing conditions, but no explanation was then possible. The colour was later attributed to a modification of ferric oxide which is stable only in the presence of ferrous oxide. This involves the existence of the two states of valency in the glass, or the simultaneous presence of FeO and Fe_2O_3. The addition of limestone to the melting glass may cause the colour to change to blue, as it may contain some material which acts as a reducing agent.

GREEN

For the production of green glasses iron, copper, and chromium are employed. Other possible agents, such as stannic oxide, are very rarely used.

The presence of 0·23 per cent. Fe_2O_3 gives an almost colourless glass which is greenish-blue in thick layers; 0·48 per cent. a light sea-green; 0·73 per cent. a bright sea-green; 1·23 per cent. a bright yellowish-green; 5·56 per cent. a deep yellowish-green, but still transparent; 8·23 per cent. a dark olive green, still transparent even in thick layers; 11·12 per cent. a dark olive green, but opaque in thick layers. The percentages stated were obtained by the analysis of test glasses, and therefore represent the amount of iron present in the finished glass.

As might be expected, the colours given by copper depend upon the conditions under which the glass is melted. A blue or green glass is obtained from copper compounds under oxidizing conditions and a ruby colour under reducing conditions. For green glasses the black or cupric oxide is used.

Chromium was discovered in 1795 in the Russian mineral crocoite, which is a lead chromate that has been used for colouring glass since the early part of last century. The name is derived from the Greek word *chrōma* (colour) and indicates that chromium compounds have vivid hues.

GREY

To produce grey or 'smoked' glass the colouring agents used are combinations of (*a*) cobalt, nickel, and uranium oxides, or (*b*) manganese, iron, and copper oxides. The glass may be of either the soda-lime or lead-potash type.

OPAL

Opal glasses fall into two main classes. First, that in which the opacifying agent dissolves, leaving the glass transparent while molten but causing it to become opaque upon cooling. Second, that in which the opacifier never wholly dissolves but remains very evenly and finely distributed throughout the molten metal. In the one type, the glass is quite transparent when gathered from the crucible and gradually becomes opal as it cools. In the other, the metal is already opal upon gathering but becomes more so as the temperature falls.

In most opal glasses the opacity is dependent upon the separation of either finely divided silica, or some metallic oxide, or both, from the mass of glass. The separation is assisted by the presence of fluorides and phosphates. A certain degree of opalescence may result from the separation of the fluoride (say as aluminium fluoride) or the phosphates themselves from the glass, but as a rule the batch is such that they remain combined as fluo-silicates and phospho-silicates, throwing the silica out of solution. The source of the opal colour in glass, therefore, may be either excess of silica, excess of a metallic oxide, e.g. of aluminium, tin, or antimony, or the presence of fluorides or phosphates.

Duval d'Adrian has sought to show that, by using the complex fluorides of silicon, boron, tin, zirconium, and titanium with the fluorides of the alkaline earths and heavy metals, and adding various mixtures of these to an ordinary glass batch, more satisfactory results are obtained than with simple fluorides.

Opal glass is being increasingly used for a wide variety of purposes. It is now commonly found in the form of illuminating globes and bowls, sheet glass, towel rails, imitation candle tubes for electric lighting, containers for pomades and other

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druggists' sundries, and linings for electroplated articles.

ORANGE

According to Sir Herbert Jackson, the famous Chinese *sang-de-bœuf*, or oxblood, glazes were due to dispersed finely divided copper in amounts of the order of 0·5 per cent., the reducing conditions under which they were made preventing any tinge of green through the presence of cupric oxide.

PURPLE

The compounds of manganese are among the oldest colouring agents used in glass. Dralle and others have stated that the purple colour is produced by the tervalent manganese oxide, Mn_2O_3, in equilibrium with MnO. To secure a deep colour with manganese the founding has to be under oxidizing conditions, as reducing agents destroy the purple tint.

Two pieces of transparent glass of an intense purple colour were sent to the late Sir William Crookes from South America. They had been found on rubbish heaps at a high altitude and had been exposed to the action of the sun over a long period. The probable cause of the colour was manganese, which would be affected by the solar rays of short wavelength, present at an altitude of 4,000 metres but absent at sea-level owing to atmospheric absorption. The colour had penetrated the whole mass, but disappeared when the glass was reheated to softening-point. By exposure to radium rays the colour could quickly be reproduced.

RED AND RUBY

Copper oxide in the cuprous form, melted under reducing conditions, gives an excellent ruby. If a copper ruby is reheated slowly for some time the particles of copper aggregate and become visible to the naked eye, giving what is known as an aventurine glass. This type of glass was first made at Murano, the name 'aventurine' being from the Italian *avventurino* (chance), indicating its accidental discovery. It has been described as a semi-opaque glass filled with golden yellow spangles.

On the rare occasions when a gold ruby glass is made today it is generally prepared from a soft lead batch containing an excess of antimony and arsenic. The gold is added in the form of a solution of gold chloride, in the proportion of 1 oz. of metal to 200 lb. of batch.

Selenium was first isolated in 1817 by Berzelius, who used the mud of sulphuric acid plants as his raw material.

Although selenium is now being used more and more as a source of red colour in glass the colour is difficult to retain, because if great care is not taken the selenium has a strong tendency to volatilize.

VIOLET

Colours ranging from violet to purple can be obtained by adding less than 1 per cent. of titanium dioxide (TiO_2) to the batch mixtures of certain borosilicate or phosphate glasses.

YELLOW AND AMBER

It is believed at present that no single element can be used to isolate spectral yellow in glass. Glasses of varying shades of yellow are, however, produced by means of cadmium, silver, sulphur, and uranium.

Carbon is very commonly used in the manufacture of yellow glasses, being introduced in the form of coke, graphite, or anthracite. It is the sulphate-containing impurities in the carbon which are the true source of the colour. This was demonstrated among others by Splitzerber, who in 1839 melted two carbon-containing batches, the first of which had 1·75 per cent. of sodium sulphate but the other none, and only the former developed a yellow colour. Again, in 1865, Pelouze obtained similar results.

In the making of amber glasses it is usual to employ a mixture of sulphur and charcoal as the colouring material. The batch must of necessity be melted in a reducing atmosphere. Experiments by Fenaroli and others led to the conclusion that the elements of the group giving yellow colours are effective in colouring glasses only when they are present as polysulphides, polyselenides, or polytellurides.

It was in 1789 that Klaproth isolated a new element, uranium, from the mineral pitchblende. He obtained sodium uranate as a bright yellow precipitate, which soon came to be used as a colouring agent for glass and glazes. When available, uranium can be used with antimony to give a stable yellow in glasses containing lead.

ACKNOWLEDGMENTS

Figures 1, 2, 3, and 5 from *Stained Glass of the Middle Ages in England and France*, by Hugh Arnold. Paintings by Lawrence B. Saint. (A. and C. Black.)

Figure 7 from *English and Irish Glass*, by W. A. Thorpe (The Medici Society).

Figures 8 and 9 from *Glass*, by Edward Dillon (Methuen & Co.).

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Plastic optical materials

D. STARKIE

Although the possibility of using transparent plastic materials in optics has long been recognized, the moulding of optical components presents much difficulty, owing largely to the tendency of the material to shrink away from the mould. This article includes an account of a method by which the surface of an original moulding can be built up so that the contours of the mould are faithfully reproduced. The method is of particular interest in connection with the construction of television receivers with relatively large screens.

From the time when plastics were first used in industry some of the transparent varieties appeared to be of value as possible new optical materials. A number of their physical properties were clearly favourable for optical work, e.g. low density, high light transmission, an outstanding toughness and resistance to severe thermal shocks, and an ability to reproduce faithfully the surface of a mould. On the other hand, when compared with glass, the transparent plastics have a relatively low resistance to scratching of the surface, less rigidity, and a relatively high coefficient of thermal expansion. Further, the range of plastic materials suitable for optical work is at the moment limited, although new transparent plastics providing an adequate range of optical constants will doubtless be synthesized and become available commercially. In attempting to assess the value of plastic materials to the optical industry, these advantages and disadvantages must be carefully considered.

THE VALUE OF PLASTICS AS OPTICAL MATERIALS

Two plastic optical materials are readily available in Britain, namely polymethyl methacrylate and polystyrene, of an appreciably higher purity than that normally associated with the commercial products. As a result of this increased purity, both materials have a relatively high softening-point and an improved craze resistance, and the development of new methods of manufacture and treatment has resulted in a freedom from strain and an optical homogeneity equalled only in the finest optical glass. The optical properties of these two materials are such that they can be used satisfactorily for achromatic lens systems. As they are pure chemical substances their refractive indices are unaffected by variations in the method of manufacture, and it is easy, therefore, to maintain the values accurate to 0·0001 from batch to batch—a factor of importance in precision optics.

The low density of the materials when compared with glass is attractive in that when plastic components are used in an optical instrument—particularly one containing massive prisms—a considerable saving in weight results. Their resistance to mechanical and thermal shocks has already made plastic optical materials valuable during wartime, and has made possible certain applications where glass is too brittle to use.

Extra care in designing an optical instrument can offset many of the disadvantages of the materials. The reduced rigidity calls for more attention in mounting if stresses causing distortion are to be avoided, although by reason of their low density plastic optical components, as compared with glass, require reduced mounting pressures to obviate displacement. The low scratch-resistance of optical plastic materials has tended to be over-emphasized, for a scratch on their surface is simply a depression with no broken edges, and the actual light-scattering area is appreciably less than with a scratch on glass. The relatively high thermal expansion again calls for care in design and mounting, and in extreme cases thermal compensating devices may be incorporated in the instrument. If the instrument is intended for use at very high temperatures it will be impossible to use plastic optical components, but a method of manufacture referred to as the 'surface-finishing' process, which has been developed recently [1] and will be described later, enables plastic optical components to be produced which are stable at temperatures up to 100° C.

It is, however, on the ability of plastic optical materials to reproduce faithfully the surface of a mould that the main interest has been centred, since it is this property which will enable the materials to make a new and extremely important

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contribution in the field of applied optics. Given a method of highly accurate reproduction from a master mould, plastic optical components can be made rapidly and cheaply. No special difficulties in making large-diameter components will be encountered, and in consequence the serious difference of price existing between large and small components made in glass will not be paralleled. Moreover, components with non-spherical or aspheric surfaces can be made at a cost sufficiently low to enable them to be used for all optical applications, once the moulds have been prepared. The ability to produce optical components with aspheric surfaces at a relatively low cost represents the chief attraction of plastic optical materials.

ASPHERIC OPTICAL COMPONENTS

It is well known that a lens, the surfaces of which are portions of a sphere, suffers from spherical aberration. With a single lens forming an image of a point source of light, the aberration causes a spreading of the image over an area instead of a concentration of the light rays to a point. If accurate concentration of the light rays to a point is to be obtained by a single lens it will have to refract the rays striking its central portion more strongly, and the rays near its perimeter less strongly, than occurs in using surfaces of spherical form. For this reason the stopping down of a lens, i.e. the screening-off of the rays from the outer edges, produces a sharpening of the image, but of course at the expense of its intensity. If the full aperture of a single lens is to be used and an accurate point image is to be obtained, it is necessary to depart quite appreciably from surfaces of spherical form and to use lenses which are flatter near the edges and steeper at the centre than on a sphere.

It is possible to make some reduction in the amount of spherical aberration in a system of lenses by selecting the shapes of the individual lenses so that the spherical aberration introduced by the negative elements is as nearly as possible equal and opposite to that introduced by the positive ones. Many ingenious, but often expensive, ways of arranging lenses with spherical surfaces in a system to reduce spherical aberration have been devised, but they unfortunately impose added restrictions in the design of certain types of optical system. Further, any introduction of additional lenses to the system adds to the losses by reflection, owing to the extra surfaces. There are certain applications where it is impossible to obtain the requisite performance using lenses with spherical surfaces, and where only aspheric surfaces can be entirely successful.

Unfortunately, the usual grinding and polishing methods of making glass optical components normally allow only spherical or flat surfaces to be worked, and the sole satisfactory way of making surfaces other than these in glass is by laborious hand-figuring of small portions of the surface until the whole area of the component has been completed. The cost of hand-figuring an optical component in this way is very high indeed, for many days of patient work by a highly skilled craftsman are involved. The use of aspheric optical components has therefore been limited to applications where cost is of secondary importance only. Many attempts have been made to produce aspheric optical components at economic prices, e.g. by using machines of special design to work the surfaces automatically, but the impossibility of constructing machines capable of working to, and maintaining, the requisite degree of precision has prevented entirely satisfactory results from being obtained.

THE 'SURFACE-FINISHING' METHOD OF MANUFACTURING PLASTIC OPTICAL COMPONENTS

Two methods of making plastic optical components by reproduction from a mould are already in operation on a manufacturing scale. The first [2] is moulding the material by compression between the two halves of an optically worked stainless steel mould, the material having first been 'preformed' to the approximate shape of the interior of the mould by machining. The second [3] is by polymerization, in which the solid polymer component is cast from the liquid monomeric form, in the presence of a suitable catalyst, inside an optically worked glass mould. Optical components made by both these methods of manufacture (which have been in operation for a number of years) have found a variety of uses.

Details of the new 'surface-finishing' process for the manufacture of plastic optical components by reproduction from a mould have been published recently. This method promises to be of importance in that it gives an extremely accurate reproduction of the interior of an optically worked mould, while the resulting optical components are entirely free from strain and are therefore stable at high temperatures.

The main ideas on which the 'surface-finishing'

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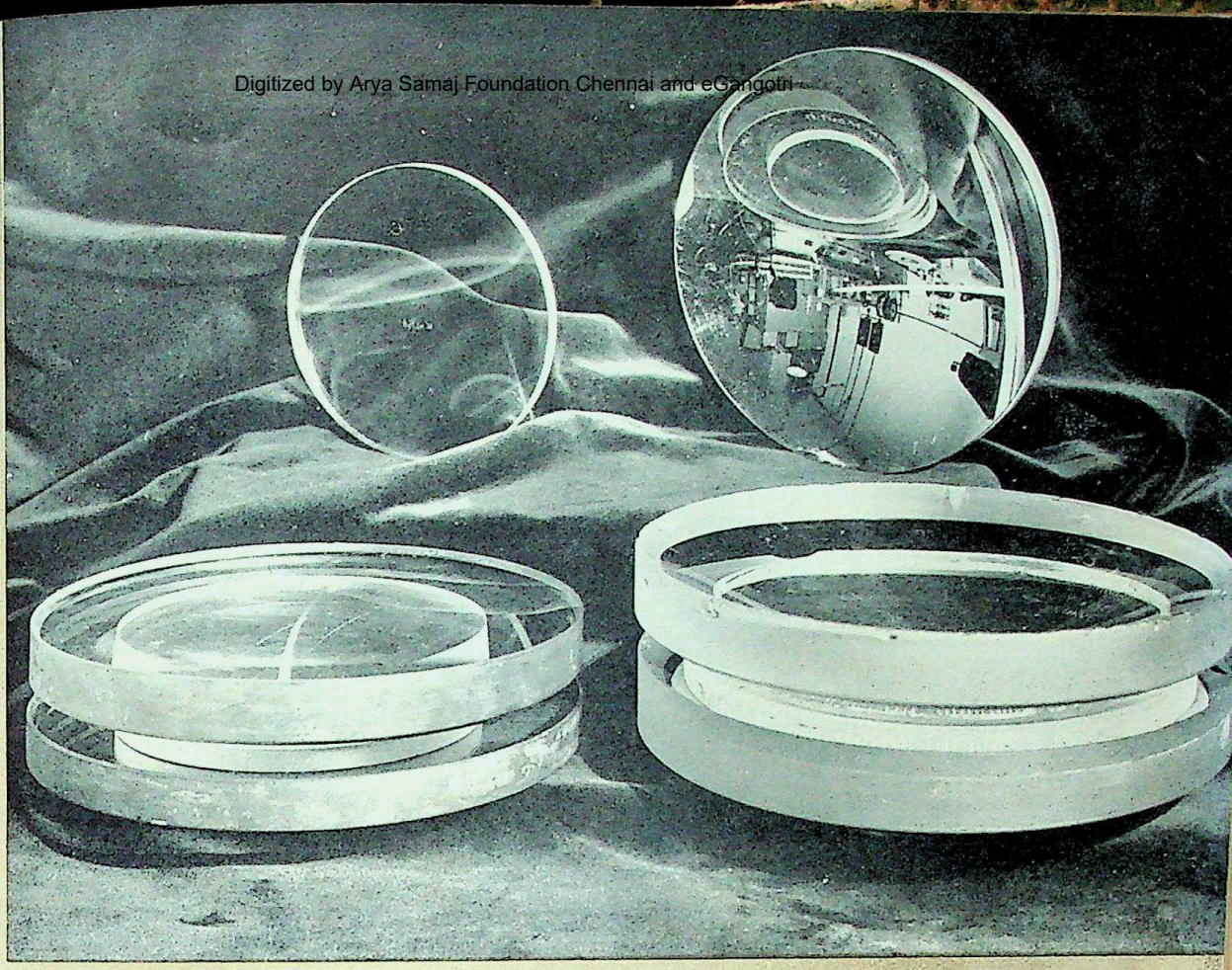
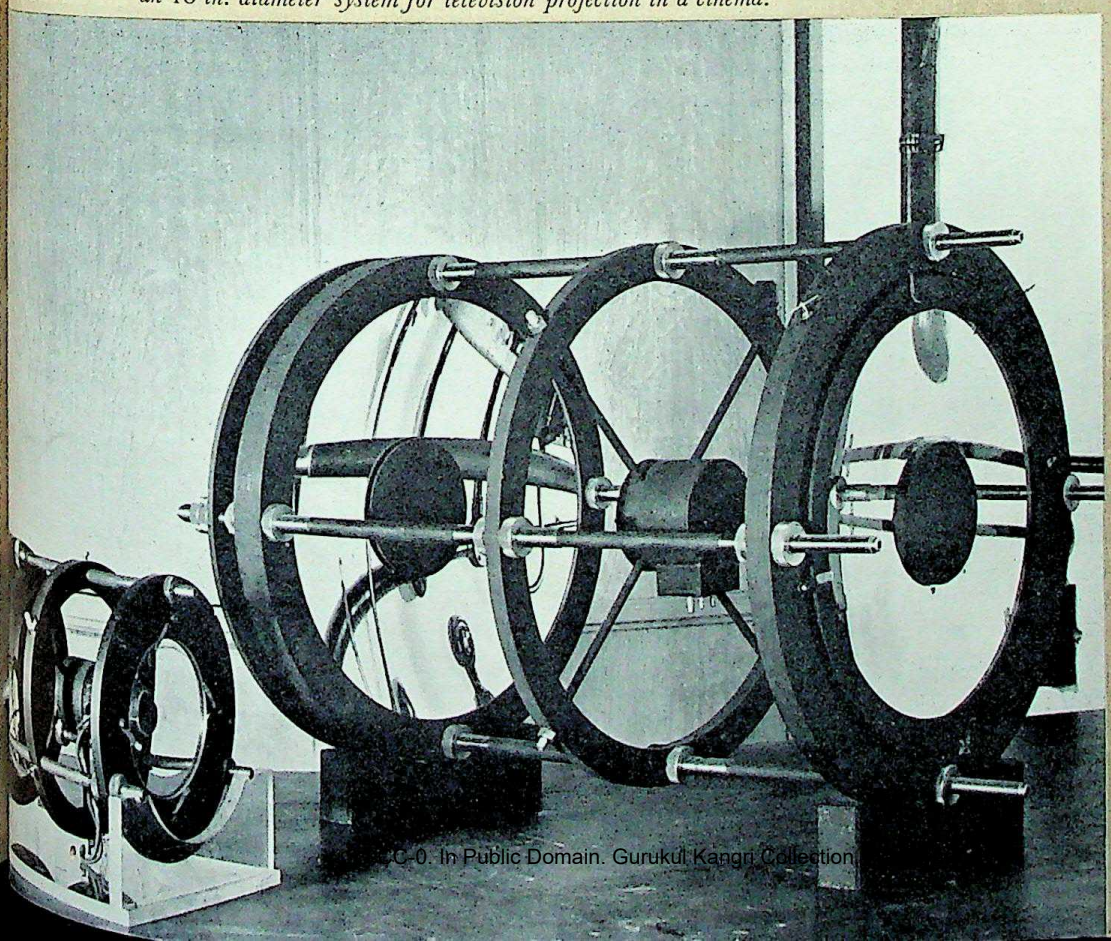


FIGURE 1 – *Two aspheric lenses with their respective moulds.*

FIGURE 2 – *An 8 in. diameter optical system for a domestic television projection receiver, and an 18 in. diameter system for television projection in a cinema.*



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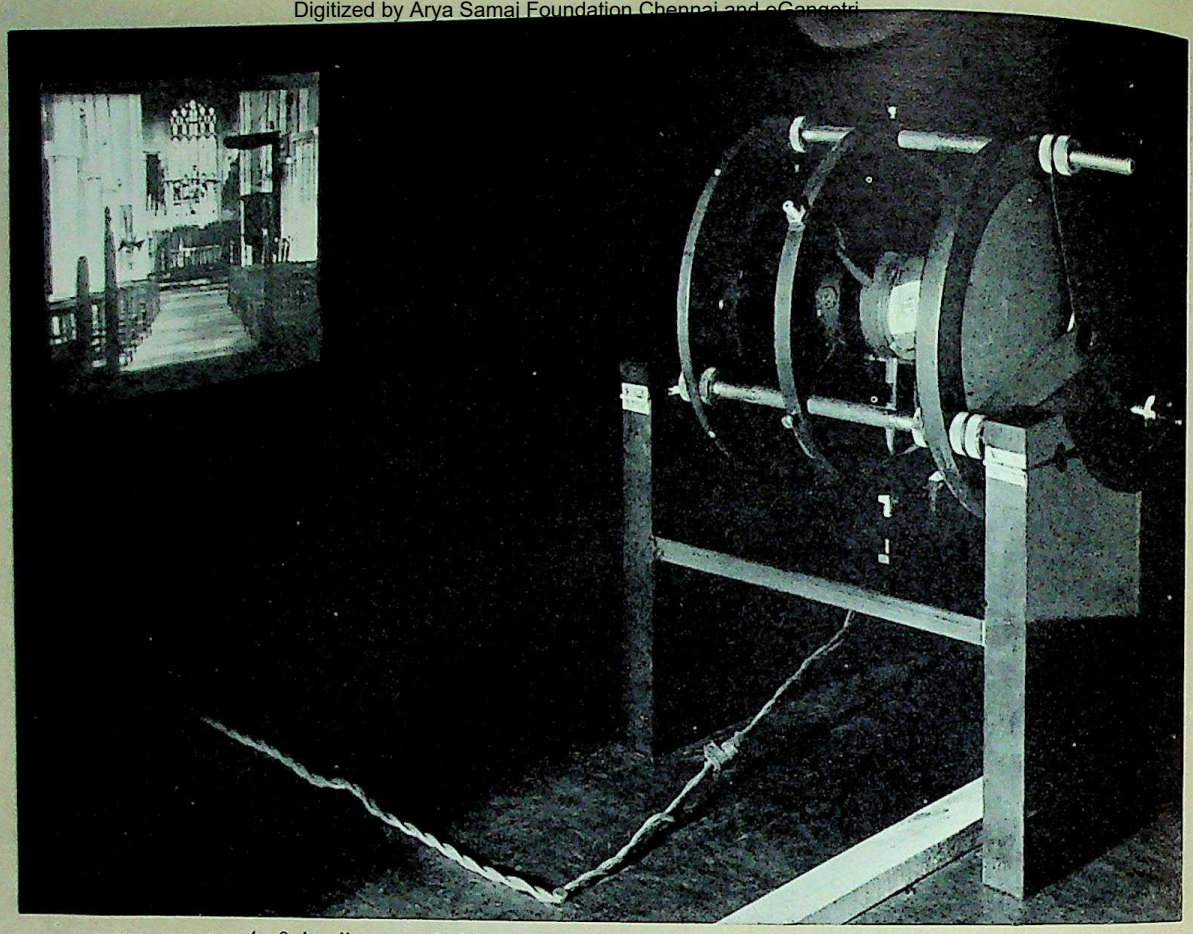

FIGURE 3 – *An 8 in. diameter television projection system projecting a picture on to a separate screen.*

process was based were (*a*) to make a strain-free preform of an optical component by some known method, and then (*b*) to build up on the surface of this preform a thin skin of the same material inside an optically worked mould until its surface made optical contact with the mould at every point. After stripping from the mould, the optical component would then be ready for immediate use. It was assumed to be essential that the use of pressure throughout the reproduction process should be avoided if perfectly strain-free, and hence stable, optical components were to be obtained.

After considerable investigation, straight polymerization, or casting from the monomeric state, in a mould, such as is used in one of the existing processes of manufacture already mentioned, was selected as the method of making the preforms. For a variety of reasons, and particularly with a view to easy operation on a manufacturing scale, polymerization by exposure to light, with a suitable photo-catalyst present in the monomer, was adopted in preference to the more usual heat polymerization for making the preforms. A considerable portion of the investigation has been concerned with the discovery of photo-catalysts and satisfactory light-polymerization conditions. There is a large contraction in volume with all the most desirable optical plastics on changing from monomer to polymer, and this increases the difficulty of making an accurate preform; but the contraction can be reduced to some extent by carrying out a partial polymerization of the monomer before filling the mould. The liquid which finally goes into the mould has a high viscosity, and the degree of polymerization of the liquid which can be allowed is limited by the fact that it must flow sufficiently easily to fill the mould. The final contraction inside the mould is taken up by allowing the two halves of the mould to be drawn together during the polymerization. When polymerization is complete, the mould containing the preform is chilled suddenly, and the two become separated owing to the fact that they do not contract equally. The preform, as it leaves the mould, is surrounded by 'flash,' which is machined off,

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after careful optical centring, in a lathe fitted with a vacuum chuck. The last stage in the preparation of the preform is a careful annealing to remove all traces of strain which may have been introduced by firm attachment to the surfaces of the mould during polymerization.

The difficulty in controlling the relatively large contraction in volume on polymerization makes it practically impossible to obtain first-class optical accuracy in the preform, and if the latter is placed back in the mould it will be found to have departed slightly from the true form. These minute spaces are filled up, therefore, by polymerizing a thin film of the same material on the surface of the preform, the film being so thin that its contraction on polymerization can be accurately controlled. Great care in carrying out this operation is required, and an exact routine procedure has been worked out. After stripping from the mould, the finished optical component is given a final edging on a lathe fitted with a vacuum chuck.

If optical mirrors are being made, a reflecting layer of aluminium is deposited on them by evaporation in a vacuum chamber, and the same apparatus can be used for coating lenses with non-reflecting films.

All the moulds used for the 'surface-finishing' process are made of glass. Glass was selected as being the hardest suitable material available in sufficient quantity. Since part of the reproduction process is by light-polymerization a transparent mould material is, of course, required.

The time necessary to make an optical component by the new process is long, although the actual handling time is short. A suitably equipped factory would contain mechanical conveyors to carry a large number of moulds through the various stages of the process, and it is hoped that such a unit will be in operation in Britain in 1948.

APPLICATIONS REQUIRING ASPHERIC OPTICAL COMPONENTS

The 'surface-finishing' process is to be applied in the first place to the manufacture of aspheric optical components, and the workers engaged on the development of the process have had to investigate both the design of such optical systems and methods of working aspheric moulds. Much progress has been made in each direction. As regards the working of the moulds, it was accepted from the beginning that hand-working methods would have to be used, and the main concentration was on devising new methods of testing the exact contours of the mould at all stages of its preparation, and on providing mechanical devices which would be helpful to the skilled craftsmen engaged on the work. New mechanical methods of testing which can be operated by the optical worker himself are used in the early stages of the mould-making, while optical tests carried out by experienced men are employed in the final stages. Complicated aspheric moulds are now produced at a much higher rate than was anticipated in the early days of the investigation. Figure 1 shows two aspheric moulds, together with lenses made from them.

An application for which an aspheric optical system is essential is television projection. In view of the urgency with which television projection systems are likely to be required, the 'surface-finishing' process has been applied primarily, up to the present, to the preparation of a range of prototypes for this application. It is generally agreed that the picture on the curved end of the cathode-ray tube which is provided by the present domestic television receiver is by no means satisfactory for viewing by a number of people, and that a much larger, flat picture is desirable. A sufficiently large cathode-ray tube would be bulky and expensive, and a much more attractive way of providing a picture of the desired dimensions is to generate a high-intensity television picture on the end of a small tube and to project an enlarged image of it on to a separate screen by means of a suitable optical system. Unfortunately the brightness of the cathode-ray tube picture in a domestic receiver is necessarily limited, and to give a satisfactory screen picture an optical system of large light-gathering power is required. A system capable of meeting all requirements is one that was designed originally for use in an astronomical telescope [4] and is usually referred to as a Schmidt system. In applying such a system for television projection, the small cathode-ray tube faces a concave mirror of large aperture which collects and projects beyond the tube a considerable percentage of the light from the television picture, while an aspheric corrector plate situated at the centre of curvature of the mirror corrects the spherical aberration of the mirror and redirects the rays of light accurately to their appropriate positions on the screen. A drawing of a Schmidt system used for television projection is shown in figure 4. With this combination of mirror and corrector plate, f numbers of 0·75 can be obtained without difficulty, even though the cathode-ray tube screens off the centre

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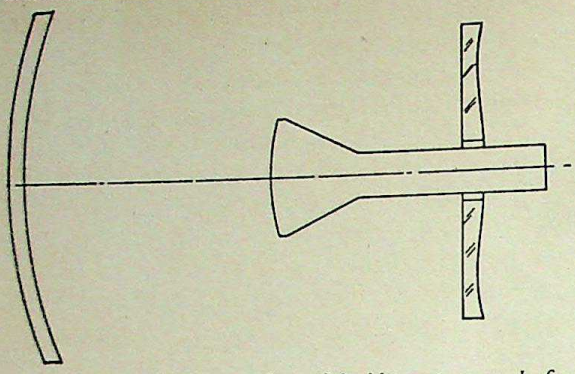

FIGURE 4 – *Diagram of a Schmidt system used for television projection.*

of the system. Provided that the mirror and corrector plate are of sufficient accuracy, a bright, sharply defined screen picture can be obtained from a relatively low-intensity cathode-ray tube picture. Once the moulds have been prepared, both mirror and corrector plate can be made by the 'surface-finishing' process at only a fraction of the cost of the same system in glass.

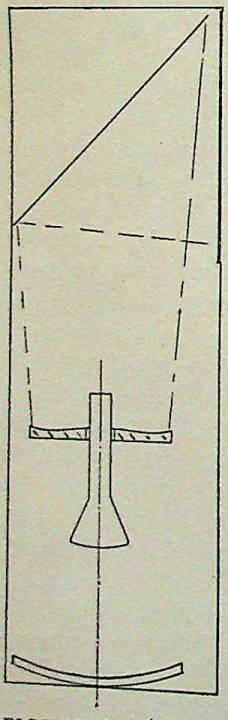

FIGURE 5 – *Arrangement of Schmidt system with 45° plane mirror in a television receiver.*

Up to the present, Schmidt systems for two sizes of projection cathode-ray tube for use in domestic receivers have been made by the new process. One system, containing an 8 in. diameter mirror, is for use with a $2\frac{1}{4}$ in. diameter cathode-ray tube, while the other, with an 11 in. diameter mirror, takes a $3\frac{1}{2}$ in. diameter tube. Both systems have a focal ratio of *f*/0·75, have a throw-distance from mirror to screen of 40 in., and give a screen picture measuring 15 in. by 12 in. Figure 5 shows how, by the introduction of a plane mirror at an angle of 45° to the light beam and a translucent screen, this 'throw-distance' of 40 in. can be accommodated in a television cabinet of reasonable dimensions. Figure 3 shows the 8 in. diameter system in operation, projecting an actual picture on to a separate screen.

There is also a demand for full-size television projection in cinemas. Here the life of the cathode-ray tube is less important than in the domestic receiver, and expensive auxiliary equipment can be installed, so that a cathode-ray tube picture of much greater brightness can be provided. This greater brightness in the tube picture is, however, offset by the fact that the projected image covers a very much greater area on the screen, and an optical system of large light-gathering power is again required. A Schmidt system of *f*/0·8 containing an 18 in. diameter mirror and with a throw-distance of 42 ft. has been made by the 'surface-finishing' process. This system, which is being used experimentally in a cinema, is giving a picture 10 ft. by 8 ft., and the brightness of the screen picture is equal to that normally obtained in a cinema by projection from a film. An optical system of still greater dimensions for use in the largest types of cinema is now being prepared. The comparative sizes of the 18 in. diameter cinema system and the 8 in. diameter domestic system can be judged from figure 2.

Although the 'surface-finishing' process has so far been applied primarily to optical systems for television projection, a wider field of application has been borne in mind. Prototype aspheric magnifying lenses which allow an operator to inspect tiny manufactured parts (using both eyes) without experiencing any sign of eyestrain have already been made. Projection systems of large light-gathering power for applications requiring either high-intensity projected pictures for viewing in brightly illuminated surroundings, or reasonable picture brightness from low-wattage lamps, are being designed, and practical trials will be carried out in the near future. These applications include filmstrip projectors for educational and publicity purposes, new types of signals and indicating devices for railways, micro-film projectors, and special projectors for use in film studios. All these systems and components, which may be required in substantial quantities, are particularly suitable for manufacture by the process of 'surface-finishing,' which will allow plastic optical materials to play an important part in the field of applied optics in the future.

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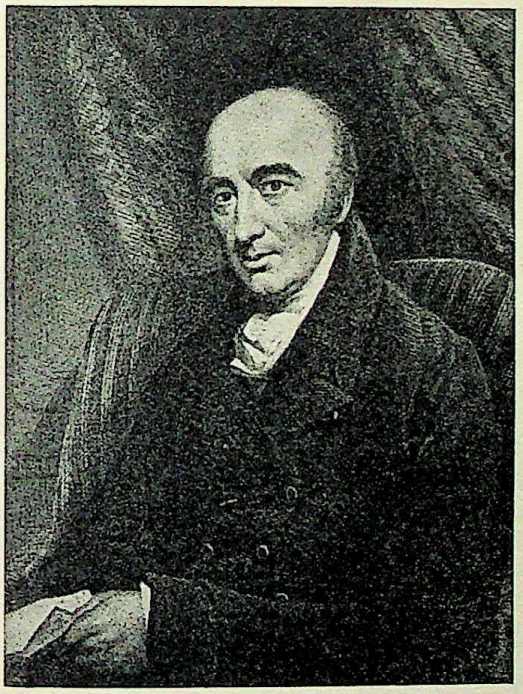
The story of malleable platinum

M. SCHOFIELD

The intractability of platinum long obscured its usefulness, and to the early Spanish miners it was nothing more than a tiresome impurity, to be discarded and dumped into the rivers of South America. Realization of the valuable properties of platinum was followed by a long struggle to render the metal malleable so that it could be fabricated into useful articles. The subsequent extensive use of platinum for laboratory and industrial equipment, jewellery, dental accessories, and other articles was a first result of pioneer work in powder metallurgy.

The history of platinum, otherwise *platina* or 'white gold,' may be divided into two parts, each of which is as absorbing as that of any other metal. There is the general history of the element, well known and set in order: a tale opening with such names as that of Julius Caesar Scaliger who, in 1557, made a first reference to a metal found between Mexico and Darien, a metal 'which no fire nor any Spanish artifice has yet been able to liquefy.' Then there is the second section, hardly as yet fully knit together: a section dealing with the making of malleable platinum, with a process which put into service a metal of which whole cargoes had lain idle as useless. This second part is indeed compelling, for it brings on the scene so many chemists of Europe: men like Scheffer, Macquer and Baumé, Achard and Lavoisier, and the less-known Chabaneau, with a goldsmith or two like Jeanety of Paris. Most important of all, it brings in William Hyde Wollaston, Thomas Cock, Richard Knight, Johnson, and Matthey to finish the early history of platinum fabrication on a triumphant note for the British school. But even today there are gaps and disjointed pieces in this story, particularly as regards the making of large platinum vessels for the concentration of vitriol. Had Wollaston sufficient elbow-room wherever he worked to construct those platinum vessels which the *Dictionary of National Biography* maintains he made himself? How much knowledge did he gain from Thomas Cock? Certain it is that the platinum still or boiling-vessel used by Sandemann was not made by Johnson, Matthey and Company as some historians have suggested, for, as D. McDonald [1] has pointed out, in 1809 P. N. Johnson was but sixteen years old and George Matthey had not been born.



William Hyde Wollaston, M.D.

In studying the fabrication of platinum, distinction must be made between early workers using, intentionally or otherwise, an alloying element to render platinum more susceptible to mechanical working and forging, and the first workers beginning the powder metallurgy of pure platinum. Among the latter Wollaston was a dominating figure. Long before Don Antonio de Ulloa, a member of the 1735 French and Spanish expedition dispatched to measure a degree of meridian at Quito, published his *Historical Account of the Voyage to South America*, primitive Indians had fished out from the Pinto river some water-worn nuggets and grains of this 'free' metal (free for anyone to take), and fashioned it into ornaments. According to Bergsøe [2] these Indians, in fashioning their nose-rings, could not have melted platinum. Not a single cast object was found, nor was any solder used. All was done by welding and cold hammering, using charcoal and the blowpipe to bring the grains into a coherent form. But there was 30 per cent. of gold present to seal together the platinum grains before the mass was sintered and then made homogeneous by hammering and

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heating. Such alloying of platinum and gold has persisted through the centuries right up to the present day: a modern example is the platinum-gold spinneret to which rayon producers have reverted after tantalum—rival to platinum—failed to stand the test. Yet platinum was to the gold-miners of the Choco district of Columbia what tungsten was to the tin-miner, or nickel ('Old Nick's metal') was to copper-miners. Gold mines were abandoned because of it, and, since the Spaniards were not averse to using gilded platinum as counterfeit, their government banned its export and ordered the metal to be dumped into rivers.

Though the ship bringing back De Ulloa was captured by the British Navy, the Admiralty 'unanimously and with pleasure' returned to him his scientific manuscripts, adding that they were 'not at war with the arts and sciences or their professors.' Hence his historical account was saved, and after its publication just two centuries ago all sorts and conditions of chemists in Europe were attracted to 'this obdurate body.' De Ulloa went on to develop the Almaden quicksilver mines, leaving it to Sir William Watson and William Brownrigg to introduce platinum. Brownrigg [3], whose *platina* from Jamaica had been given him by a relative, Charles Wood, told of its high melting-point and its refractoriness (noted by Wood), and he believed the Spaniards had melted it and cast it into sword-hilts, buckles, and snuff-boxes. Such first dabblings with platinum were extended by the Swede Scheffer [4], who in 1752 succeeded in fusing a sample of 'white gold' (obtained from Watson in London) by the use of arsenic; and by Lewis [5], whom Scheffer anticipated and who published his observations in the *Philosophical Transactions*. In 1772 von Sickingen rendered platinum malleable by alloying it with gold and silver. He also dissolved it in *aqua regia*, added ammonia, ignited the precipitated ammonium platinichloride, and hammered the fine platinum to effect cohesion.

Such an important step towards producing malleable platinum by way of the metallic powder was the practical realization of an idea of Antoine Baumé, who suggested that platinum could probably be forged and welded as iron had been worked among the ancients. In mentioning Baumé one must give credit to several Frenchmen, chemists and others, who made persistent efforts to harness the metal. Thus M. de l'Isle [6] in 1770–4 used the ammonium platinichloride method to obtain finely divided platinum, and agglomerated this to the malleable form. De Morveau [7] tried alloying with lead as well as the arsenic method. Achard, father of the beet-sugar industry, also used arsenic and is said to have made the first platinum crucible. There was also the Abbé Rochon [8], director of the Marine Observatory at Brest, whose method was to purify platinum grains 'in a strong fire' with nitre and sulphate of soda, adding one-eighth part of the tin–copper alloy used for common specula, exposing the mixture to 'violent heat,' and fusing it before pouring it into a mould to give a large speculum weighing 14 lb., with a diameter of 8 in. and a focal length of 6 ft. To continue the part played by Frenchmen, Lavoisier [9] in his *Observations sur le platine* told how Baumé tried lead and bismuth as alloying metals; others used arsenic, which was removed by vaporizing on subsequent heating; and Rochon used copper and tin capable of being dissolved in nitric acid after reducing, leaving platinum as a black powder. Lavoisier doubted whether this could be used in large-scale work, and then referred to Jeanety as the man worthy of most merit. The jeweller Jeanety of Paris, receiving some platinum ingots from Chabaneau, made platinum snuff-boxes, a coffee pot shown by Lavoisier to the Academy, watch chains, and platinum buttons. Berthollet and Pelletier credit Jeanety with perfection in platinum-working by alloying with arsenic in a crucible, obtaining a button, breaking this up and treating the product with white arsenic and refined potash, and finally vaporizing the arsenic—an eight-day operation. To Jeanety, let it be noted, came the *savants* to buy platinum crucibles and the Academy to get bars of platinum.

Jeanety's platinum was supplied by Pierre François Chabaneau, that versatile yet almost unknown French chemist, who deserves a paragraph to himself. While Jeanety was the first to make fairly pure platinum sponge in quantity and to fabricate it at a white heat, he continued with his arsenic when he failed to discover Chabaneau's method. Chabaneau [10], a native of Dordogne, was expelled from his theology school and took a mathematical teaching post at Passy, where he studied by firelight for the next day's teaching. It was while he was giving some public lectures that certain Spanish members of the audience were attracted by him and persuaded him to go to Spain. So we hear of Chabaneau going to Vergara to teach physics, collaborating with de Elluyar of tungsten fame, and being installed by Charles III in a science chair at Madrid, with a royal palace as lodgings and a valuable library and well-equipped laboratory at his disposal. At this period Spain suddenly

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realized that her South American platinum, hitherto despised, was an asset. It was turned over *en masse* to Chabaneau, thus beginning what has been called 'the platinum age' in Spain. Chabaneau had a difficult problem: chemistry was not yet sufficiently advanced to bring the recognition that platinum could be malleable at times and brittle when iridium was present, and that the original ore contained a number of metals like gold, mercury, lead, copper, and iron as well as those of the platinum group. 'Away with it all! I'll smash the whole business!' cried Chabaneau on more than one occasion as he threw his apparatus out of doors in a tantrum. 'You'll never again get me to touch the damned metal!' Yet it was a different Chabaneau who one day placed on the table of the Marqués de Aranda a 23 kg. ingot of malleable platinum in the shape of a 10 cm. cube—which the Marqués found surprisingly heavy. Chabaneau and his fellow-worker Cabezas made utensils and ingots in their prosperous business, and produced platinum crucibles for the use of Joseph Louis Proust. The king would often come to the laboratory to watch Chabaneau at work, but what was more important was the grant of a life pension and letters patent of 1783 establishing priority for Chabaneau's method.

While the goldsmith Jeanety continued to supply platinum apparatus from the metal processed by the Scheffer-Marggraf-Achard method, involving the use of arsenic and its subsequent volatilization, and while Count Apollos Moussin-Poushkin [11] in 1805 was using a mercury amalgamation method with the removal of mercury by the same means, the English school of platinum fabrication was developing. Richard Knight [12], for example, published a *New and Expeditious Process for rendering Platinum Malleable*. This involved compression of ammonium platinichloride into a hollow conical crucible with cover, the reduction to platinum at a strong white heat in an air furnace, and the hammering-in of a red-hot stopper to yield a platinum button which was then hammered and further heated. There was also Thomas Cock [13], who reduced platinum to a sponge in the platinichloride process and followed this by compression in an iron mould with a screw press for removing air. When volatiles had been driven off at a white heat, the platinum was hammered 'in all directions' on an anvil, and after a borax-flux treatment the working was repeated. Cock was a brother-in-law of P. N. Johnson and worked in William Allen's laboratory at Plough Court, London. He is believed to have worked on platinum from 1800 to 1809; he then disappeared for a time and later is heard of helping his brother-in-law and leaving a son to carry on the business. He seems to have communicated his method to Wollaston at Allen's request [14] and to have rediscovered Chabaneau's process—as did Knight (the latter, according to one report, being the first to fabricate large sheets of pure platinum free from flaws [15]).

Yet among the early platinum-workers William Hyde Wollaston stands out as the most prominent figure. There is a hint that Wollaston [16], after seeing Cock's work, took away some ideas which he did not acknowledge—ideas extra to whatever Cock told him. Whatever the truth of this may be, his own contribution is so great, as D. McDonald [17] remarks, that anything Cock provided could have been only a minor part. Wollaston, working in his secret laboratory, was the first to fix the composition of native platinum, and was the collaborator of Smithson Tennant in the study of palladium, osmium, iridium, and rhodium. He knew the exact proportions of *aqua regia* mixtures which would leave iridium undissolved, and how to expel volatiles from the platinichloride without allowing the platinum particles to adhere. But he was a business man and made a fortune of £30,000 from platinum fabrication, using it as a means of retiring at 34 to devote himself to scientific studies. He seems to have obtained platinum on a fairly large scale, fabricated it into laboratory ware (thus making this country independent of manufacturers abroad), and then turned his attention to making those large boilers for sulphuric acid which could not have been made by Johnson and Matthey. Wollaston was secretive and published nothing until, just before his death, he decided to broadcast his method in the Bakerian Lecture [18] of 1828. 'As, from long experience, I probably am better acquainted with the treatment of Platina, so as to render it perfectly malleable, than any other member of this society . . .' —so he opens his dissertation in which he tells how he avoided dissolving iridium by dilution of the *aqua regia*; how he rubbed the finer grey platinum powder in his hands and the coarser in a wooden pestle and mortar so as to avoid burnishing the particles. He washed the powder by levigation, made a mud of specific gravity 4·3 with water, compressed this to a cake of specific gravity 17–17·7 in a conical brass barrel-mould greased with lard, and used a lever press in place of Cock's screw press. In Wollaston's hands every part of the process was subjected to minute care and attention. He used first a charcoal fire to remove

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moisture and grease and give finer cohesion, and then a wind furnace fired with Staffordshire coke to effect cohesion before hammering, reheating, and forging. As Thomas Thomson [19] put it, 'Wollaston first succeeded in reducing platinum into ingots in a state of purity and fit for every kind of use.' With his warnings against work-hardening the powder, Wollaston was an early powder-metallurgist, a pioneer in that struggle which has given us tantalum, tungsten, molybdenum, and niobium.

Wollaston's success had its fruits both in the laboratory and on a large scale. Instead of relying on France and Jeanety's followers for apparatus, chemists like Berzelius would apply to London for malleable platinum, and later, after Wollaston's method was published, were enabled to renew platinum apparatus made by less satisfactory methods.

On the commercial side it was for concentrating vitriol in stills or boilers that malleable platinum was brought to prominent use. It was Sandemann, a chemist member of the British Mineralogical Society, who maintained a small chemical works at Thames Bank and used such large boiling vessels, although Richard Farmer seems to have been the first sulphuric-acid maker to adopt this process, according to Knight's *English Encyclopaedia* of 1857 [20]. At his works on Kennington Common, Farmer engaged Wollaston to supervise the construction from his own platinum of a 323½ oz. troy vessel at a cost of £300; other vessels followed in 1820 totalling 828 oz. and costing £685. Wollaston charged for the weight of platinum supplied and for the workmen's wages, his own services being free. Sandemann in December 1809 had a vessel made of deep circular form, the weight being 423 oz. and the capacity 300 lb. of sulphuric acid, for use under a lead-chamber plant. This was the vessel previously referred to, which could not have been made by Johnson and Matthey.

With the death of Wollaston other makers of malleable platinum were left to carry on in London, Paris, and Russia. In France there were Desmoutis and Quennessen. In London were P. N. Johnson, founder of Johnson, Matthey and Company, who worked with Cock, his brother-in-law, with W. J. Cock the son, and others in business as Johnson & Sons. Johnson and Matthey soon won first place among such producers, and kept it through the agency of George Matthey and John Scudamore Sellon, having access to the considerable resources of Russia for their raw material. Half-way through last century the British concern had captured the world market, all this following a fruitful collaboration between Matthey and Sellon on the one hand and Deville and Debray [21] on the other. In 1861 platinum boilers for treating sulphuric acid were shown at a London exhibition, these being made by a 'patent autogenous soldering.' More than 160 concentrating vessels of from 20 to 160 gallons' capacity had been made by the old system of gold-soldered joints, but the patent soldering used the oxy-hydrogen blowpipe method as first described by Robert Hare before the Chemical Society of Philadelphia in 1801. In 1878 at the Paris Exhibition [22] Johnson and Matthey exhibited platinum ware, Deville and Debray's melting-process having replaced the compression-hammering method in producing such large ingots as were then prepared. 'Sponge' ingots are superior to unalloyed melted metal, provided the sponge is pure and that all the precautions given by Wollaston are observed. Such is the early story of malleable platinum. Further important advances in the metallurgy of the platinum metals have of course been made since those pioneering times, but they lie outside the scope of the present article.

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The metabolism of nitrogen in soil

J. H. QUASTEL

From the bland assurance and circumstantial detail with which many elementary textbooks present the 'nitrogen cycle,' students might be pardoned for believing that the problem had been solved once and for all. Professor Quastel has a very different story to tell. He shows that the study of nitrogen metabolism in soil is still in its comparative infancy, and that while many of the basically significant facts have been elucidated there are very numerous phenomena of great interest—and great difficulty—yet awaiting full investigation.

Nitrogen metabolism in soil covers the vast sequence of chemical changes undergone by the nitrogen molecule in biological processes taking place in soil, from its initial fixation until its final liberation into the atmosphere. The main processes comprising this cycle of changes are as follows:

1. *The transformation of atmospheric nitrogen by soil micro-organisms into substances nourishing microbe and plant.* This process is generally known as biological nitrogen fixation, and is accomplished largely by two sets of organisms, one consisting of the root-nodule bacteria living in symbiosis with certain leguminous plants, and the other consisting of organisms living in the soil independently of plants.

2. *The transformations in soil of organic nitrogen compounds arising from autolysis of all forms of biological material, or from the excreta of animals, or from the products of metabolism of living soil organisms, into ammonium ions.* These processes are accomplished by a great variety of soil micro-organisms which, while developing aerobically or anaerobically on organic nitrogen compounds, produce ammonium ions as part of their metabolism; or they may be brought about by the action of hydrolytic or oxidizing enzymes present in soil micro-organisms, whether they are proliferating or not.

3. *The conversion of ammonium cations into nitrite and nitrate anions.* This process is generally referred to as soil nitrification, and is accomplished largely by two groups of organisms, *Nitrosomonas* (also *Nitrosocystis* and *Nitrosospira*), which forms nitrate from ammonium ions, and *Nitrobacter* (also *Nitrocystis* and *Bactoderma*), which converts nitrite ions into nitrate ions.

4. *The reduction of nitrate into nitrite and finally into ammonium ions or into free nitrogen.* Reduction of nitrate into nitrite and ammonia is accomplished by many micro-organisms, and is a process which has been much investigated. The biological process of nitrogen production, or of formation of oxides of nitrogen, from nitrates and nitrites, is, however, not so well understood. Nitrates form the main source of nitrogen for plant life growing in soil, and therefore ultimately for all animal life.[1] The nitrogen returns to the soil largely in organic combination, and undergoes the changes mentioned in process 2. Nitrogen is not lost to the atmosphere in its transformations in the intact plant or animal.

The total combined nitrogen on earth would increase, as a result of the biological catalytic processes of soil which fix atmospheric nitrogen, were it not for the fact that mechanisms exist which provide for the release of free nitrogen from combined forms such as nitrite or ammonia. The process whereby reduction of nitrate (or nitrite) takes place to form gaseous nitrogen (or oxides of nitrogen) is known generally as denitrification.

BIOLOGICAL NITROGEN FIXATION

It is now known that certain specific micro-organisms working symbiotically with legumes can fix atmospheric nitrogen. The following is a brief history of this discovery.

Boussingault in 1837 carried out the first quantitative field and laboratory experiments, indicating that fixation of atmospheric nitrogen takes place during the development of legumes such as clover, peas, and lucerne, whereas no such fixation occurs during the growth of such crops as wheat or oats. Liebig (1843, 1852) opposed the view that free nitrogen of the atmosphere is assimilated by the plant. He considered that the beneficial effects of the legumes are due to their large leaf surfaces, which offer greater areas for absorption of atmospheric ammonia. Ville (1855), however, showed that atmospheric ammonia is insufficient in quantity to account for the observed increase of fixed nitrogen in the development of legumes. The subject remained in a confused state until after the

[1] Ammonium nitrogen is, however, assimilated by many plants growing in soils which do not support ready nitrification, e.g. certain grasses and forest trees.

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work of Lawes, Gilbert, and Pugh at the Rothamsted Experimental Station. In 1851 these investigators began experiments in an attempt to explain the results of field trials which had extended over sixteen years. The data had demonstrated that plots cropped to non-legumes without addition of manures give rise to only low yields, while plots cropped to legumes maintain high yields even without any manurial treatment. Moreover, if a non-legume follows a legume in a rotation, the yield is as high as if the field has been previously in fallow for a year. This occurs in spite of the fact that a large quantity of nitrogen is removed in the preceding leguminous crop. Liebig's explanation of absorption of atmospheric ammonia was found to be erroneous, partly because too small quantities of ammonia are absorbed from the air and partly because legumes and non-legumes behave very differently.

The logical deduction appeared to be that legume development in the field is accompanied by fixation of atmospheric nitrogen. Careful pot experiments, however, by Lawes and his colleagues (1861) gave rise to the conclusion that no fixation of molecular nitrogen takes place during the development of either legumes or cereals. The view was therefore held, and accepted for the following twenty-five years, that plants cannot fix atmospheric nitrogen. The clear-cut results of the Rothamsted field experiments still remained unexplained. The classical work of Hellriegel and Wilfarth in 1886 eventually clarified the situation. They were able to show that certain bacteria in the soil infect legumes, forming nodules which enable the plants to use atmospheric nitrogen; these bacteria have no infective power on cereals.

The organisms responsible are known as root-nodule bacteria or *Rhizobia*. They were first isolated in pure culture by Beijerinck.

NITROGEN FIXATION BY *RHIZOBIUM*

Little is known as yet of the mechanism of nitrogen fixation by the root-nodule bacteria in association with the plant. Neither the host plant nor *Rhizobium* can independently fix nitrogen, except under very specialized conditions which are under investigation. It is obvious that there must be some chemical interchange between plant and bacteria, taking place *in vivo*, which is largely responsible for nitrogen fixation. Before considering this chemical interchange, a few of the biological aspects of the association between *Rhizobia* and host plant may be mentioned.

When the seed of a legume develops in a soil containing *Rhizobia* the latter are attracted to the region of the developing root hairs. The result of the presence of the *Rhizobia* in the near neighbourhood of the root hairs is to produce a 'curling' or deformation of the hairs. Specific chemical substances are responsible for this 'curling,' for bacterial extracts in absence of *Rhizobia* are found to be as effective as the organisms themselves. The response is biologically nonspecific and may be induced by extracts of bacteria other than *Rhizobia*. At the site of deformation of the root hair, *Rhizobia* invade the root tissue and proliferate within the hair in the form of a thread directed towards the cells of the root. The migrating bacteria are embedded in a gum, and an infection thread is developed. A sheath is laid down by the host cells around the embedded bacteria. Cell division is stimulated, the newly formed tissues are invaded by more bacteria, and thus a nodule is formed. Thimann (1936) concludes that the *Rhizobia* produce in the root hair a specific compound, probably indoleacetic acid, which is responsible for the local stimulation of the host cells. Both the bacteria and the host cells fail to proliferate as the nodule becomes older, and finally the tissue becomes necrotic. The nodule softens, its interior is digested, and it finally sloughs off. The *Rhizobia* return to the soil.

There is evidence that the deformation of the root hair, essential as a preliminary to the invasion of the *Rhizobia*, is also accomplished by indoleacetic acid, a common metabolic product of bacteria. It is known that indoleacetic acid and related plant 'hormones' have but a transitory existence in soil, owing presumably to speedy decomposition by bacteria. It follows, therefore, that metabolic conditions in the soil in the near neighbourhood of the germinating legume must be such as to enable a sufficiently high concentration of indoleacetic acid to accumulate to bring about the physiological response in the root hairs. Though such a concentration may be small—of the order of one part in 100,000,000—a relatively high rate of production may be necessary to counteract the local destructive forces as work. It is known, too, that indoleacetic acid at low concentrations may be toxic to seed germination, and that tryptophane in presence of soil bacteria will induce toxicity. Thus metabolic conditions in soil will greatly influence seed germination.

The presence of combined nitrogen (e.g. nitrates or ammonium salts) in the soil in which the host plant is growing apparently makes the plant resistant to attack by *Rhizobia*. It has long been

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known that nitrates impede the development of nodules on legumes: fewer root hairs are deformed and fewer nodules are formed.

Light may be thrown on the chemical association between *Rhizobia* and host plant by the recent discovery (Kubo, 1939) that haemoglobin exists as a red pigment in the nodules of legumes. Keilin and Wang (1945) have confirmed this discovery, finding that the pigment of soya-bean nodules is a haemoglobin with a characteristic absorption spectrum.

Although haemoglobin is very widely distributed in nature its presence has been considered as general only in vertebrates. This view may have to be seriously modified by the discoveries that the pigment exists in a ciliate *Paramoecium* (Sato and Tamiya, 1937) and in the root-nodules of legumes. Neither the plant cells alone nor the *Rhizobia* grown separately synthesize haemoglobin. 'It is only when root cells are invaded by a specific symbiotic micro-organism and begin to proliferate that haemoglobin is formed. *Rhizobium* not only induces growth and multiplication of cells but also supplies these proliferating cells directly or indirectly with a factor necessary for synthesis of haemoglobin' (Keilin and Wang, 1945). The facts point to the possibility that in the root-nodule haemoglobin itself, or the processes connected with its synthesis, may be directly linked with nitrogen fixation. On the other hand, haemoglobin may act only indirectly by securing in the root-nodule optimal conditions for oxidative processes with which nitrogen fixation may be associated. Carbon monoxide is known to inhibit symbiotic nitrogen fixation at low pressures, at which it reacts with haemoglobin. Virtanen and Laine (1946) have found methaemoglobin also in root-nodules, and consider that an equilibrium exists there between haemoglobin and methaemoglobin. As a result of experiments on the excretion of nitrogen products by legumes they have made an hypothesis, expressed in the following equations, relating nitrogen fixation to valency changes in haemoglobin. (They make the proviso that the hydroxylamine mentioned in the first equation need not appear directly from the molecular nitrogen but possibly only after a number of intermediate stages.)

Keilin and Smith (1947), however, deny the presence of methaemoglobin as a normal constituent of the root-nodule, and do not support the view that nitrogen fixation involves valency changes in haemoglobin.

Facts obtained by Virtanen and Laine in favour of their view are as follows:

1. Cultures of legumes in sterile sand containing the proper species of *Rhizobia* excrete *l*-aspartic acid and β-alanine, the latter probably arising from the former by decarboxylation. The excretion takes place only when nitrogen is being fixed.
2. A small quantity of oxalacetic oxime is also excreted under the same conditions.
3. Free oxalacetate is formed in pea plants actively fixing nitrogen.
4. Excised nodules, intact or crushed, are able to fix atmospheric nitrogen in presence of oxalacetate but not in its absence.

There have been failures to confirm these phenomena, but Virtanen and Laine's view offers a useful working hypothesis.

NON-SYMBIOTIC NITROGEN FIXATION

Winogradsky in 1893 found that an anaerobic soil organism, *Clostridium pastorianum*, will fix free nitrogen when supplied with glucose, the amount of nitrogen fixed being proportional to the amount of glucose broken down. The fixation of nitrogen is inhibited by the presence of ammonium salts, and this inhibition may be counteracted by an increase in the glucose concentration. Thus the ratio of carbohydrate to combined nitrogen determines the rate of fixation of nitrogen. An interesting feature of this organism is that it loses its power of nitrogen fixation during prolonged cultivation on artificial media, but the power is restored by culture of the organism once again in soil.

Beijerinck in 1901 isolated from soil and mud two aerobic organisms capable of fixing atmospheric nitrogen. They are *Azotobacter chroöcoccum* (the more common form) and *Azotobacter agilis* (the motile variety). Unlike *Clostridium*, *Azotobacter* does not lose its power of fixing nitrogen on prolonged culture on synthetic laboratory media. A striking fact concerning *Azotobacter* is that it requires for its metabolism the presence of traces of molybdenum or vanadium. A positive effect of

$$N_2 + \text{methaemoglobin (Fe}''') \rightleftharpoons NH_2OH + \text{haemoglobin (Fe}'') \quad \ldots\ldots\ldots\ldots (1)$$

$$\underset{\text{(Hydroxylamine)}}{NH_2OH} + \underset{\text{(Oxalacetic acid)}}{COOH.CO.CH_2.COOH} \rightleftharpoons \underset{\text{(Oxalacetic oxime)}}{COOH.C(NOH).CH_2.COOH} + H_2O \quad \ldots\ldots (2)$$

$$COOH.C(NOH).CH_2.COOH \xrightarrow{\text{Reduction}} \underset{\text{(Aspartic acid)}}{COOH.CH(NH_2).CH_2.COOH} \quad \ldots\ldots\ldots (3)$$

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molybdenum on the growth of the organism can be observed at a concentration of 1–3 parts in 10^{12}. Burk and Horner have found that molybdenum is not only required for the assimilation of free nitrogen but is necessary for the utilization of combined nitrogen (as of asparagine or nitrate) by this organism. Tungsten will to some extent replace molybdenum. *Azotobacter* and *Clostridium* are apparently the most widely distributed non-symbiotic nitrogen-fixers in soil; they are found also in salt and fresh water, often in association with algae.

In arid soils relatively poor in organic matter, micro-organisms form more than their usual proportion (about 5 per cent.) of the organic matter, and this is chiefly due to the marked development of *Azotobacter* under the alkaline or saline conditions of such soils. In the chestnut soils of south-east Russia, where almost the whole of the organic matter is in the form of micro-organisms, there are up to 900,000,000 *Azotobacter* cells per gram of soil.

The most important single factor influencing nitrogen fixation in soils is the presence of nitrate. With both *Clostridium* and *Azotobacter* the presence of utilizable combined nitrogen diminishes the rate of nitrogen fixation, ammonium or nitrate nitrogen being effective in this way. Inhibition of fixation by *Azotobacter* is complete in the presence of ammonium nitrogen at a concentration of 0·5 mg. of nitrogen per 100 ml. The presence of nitrate or of ammonium salts in the soil also makes legumes resistant to attack by *Rhizobia*, fewer root hairs and nodules being formed. The net result is that, when excess combined nitrogen is available in the soil, little or no fixation of atmospheric nitrogen takes place. The presence of carbohydrates diminishes the effect due to the combined nitrogen.

NITROGEN FIXATION BY *AZOTOBACTER*

Kostytschew and his colleagues (1925) came to the conclusion that the initial process in fixation of nitrogen by cultures of *Azotobacter* is the formation of ammonia, and Winogradsky (1930) discovered that ammonia is formed when *Azotobacter* proliferates on a silica gel in the absence of combined nitrogen. Burk and Horner (1936) opposed the conclusion that ammonia is the first product of nitrogen fixation. They claimed that the ammonia arose in a secondary manner by oxidative deamination of cell organic matter. Winogradsky (1938) pointed out that pure cultures of *Azotobacter* cannot break down organic matter to ammonia, and concluded that the appearance of ammonia in pure cultures of this organism indicates a direct reduction of molecular nitrogen. Burk and Horner (1939), however, still maintain that the ammonia excretion of *Azotobacter* is largely independent of the form of nitrogen supplied (free or combined).

Using a manometric technique which made it possible to study nitrogen fixation by *Azotobacter* in a more quantitative manner than had hitherto been possible, Burk and his colleagues (1930, 1934) have found (1) that the respiration of *Azotobacter*, which is extremely high, is greatest at pressures of oxygen below that in air; (2) that the presence of utilizable combined nitrogen (ammonia or nitrate) diminishes the rate of free nitrogen fixation; (3) that calcium ions (or strontium ions) are necessary for the fixation, and that the substances which immobilize the calcium by forming insoluble salts with it inhibit the nitrogen fixation; and (4) that molybdenum (or, to a less extent, vanadium) has a highly beneficial effect on *Azotobacter* growth in free nitrogen.

Burk and his colleagues have suggested that the following enzyme mechanism is responsible for nitrogen fixation in *Azotobacter*:

$$N_2 + E \rightleftharpoons N_2E \text{ (rapid)},$$
$$N_2E \longrightarrow E + P \text{ (slow)}.$$

E refers to a specific enzyme (*nitrogenase*) which combines reversibly with the nitrogen molecule to form the enzyme-substrate complex N_2E. This breaks down irreversibly into E and the products P, which corresponds to an increase in *Azotobacter* cells. The total system responsible for fixation has been termed *Azotase*.

AMMONIA FORMATION

It is known that nitrogen compounds in plant residues are decomposed in soil to form ammonia so long as the ratio of carbon to nitrogen in the organic matter does not greatly exceed 10:1.

Proteins and other nitrogenous compounds are broken down in soil by a variety of organisms, the ultimate nitrogenous product being ammonia. Whether the ammonia appears or not depends on the rate of proliferation of organisms in the soil requiring the ammonia nitrogen for their own synthetic operations. If ample utilizable non-nitrogenous material, such as carbohydrate, is present, the ammonia nitrogen will not appear, as it is entirely used for building up fresh bacterial or fungal matter. The amount of nitrogen liberated as ammonia in protein decomposition may be represented as follows:

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$$\left\{\begin{array}{c}\text{Nitrogen of}\\ \text{substance}\\ \text{decomposed}\end{array}\right\} - \left\{\begin{array}{c}\text{Nitrogen synthesized}\\ \text{by micro-organisms}\\ \text{for growth}\end{array}\right\} + \left\{\begin{array}{c}\text{Unassimilable}\\ \text{nitrogen}\end{array}\right\} = \left\{\begin{array}{c}\text{Ammonium}\\ \text{nitrogen}\end{array}\right\}$$

Proteins being rich in nitrogen yield ammonia in relatively large amounts. Many organisms are involved in ammonia formation, the mechanisms of which may vary from organism to organism. If the proteins are broken down to amino-acids, these may yield ammonia by the exercise of oxidase systems of either resting or proliferating micro-organisms. Little is known, however, of the modes of decomposition of nitrogenous organic matter in soil.

NITRIFICATION

The metabolic process whereby ammonia and organic nitrogenous material in soil are converted finally to nitrate was shown by Schlossing and Muntz (1877, 1874), from a study of the purification of sewage waters by land filters, to be a biological process. Warington found that soil nitrification is inhibited by application of chloroform and carbon disulphide, and both he and the Franklands (1890) established the fact that nitrification proceeds in two stages, ammonia being oxidized to nitrite and the nitrite to nitrate. Winogradsky (1890, 1891) succeeded in isolating the responsible organisms in pure culture, an achievement of great importance in the study of autotrophic organisms. Organic matter was shown to be unnecessary for the metabolism, and in fact it was stated to be injurious to their development. Warington made it clear that the final fate of nitrogen in the soil is the formation of nitrate. Progress in the study of soil nitrification since the end of last century has been extraordinarily slow. Stevens and Withers (1910) showed that nitrification in soil differs in at least one important aspect from that in the artificial (silica gel) media first elaborated by Winogradsky. They demonstrated that nitrification is inhibited far less in soil by the presence of added organic matter than in laboratory media. Much important work on the behaviour of nitrifying organisms in pure culture in laboratory media has been carried out by Meyerhof (1916, 1917) and others, but the general relations between the results obtained in such culture experiments and those obtained in soil are obscure. Albrecht and McCalla (1937) have summarized the position thus:

> The conditions controlling nitrification in aqueous solution have been studied very specifically. Less definite controls and less refinement in methods have been obtained for studies of this process within the soil. The complexity of a sand, silt, and clay mixture, as soil, prohibits an accuracy great enough to encompass all the various chemical aspects of so delicate a process as nitrification.

Lees and the present writer (1944, 1946) have carried out experiments on the mode of transformation of nitrogen compounds into nitrate in soil, using a new technique with which metabolic events in the soil can be studied with greater accuracy than has been accomplished hitherto. In essence, the attempt has been made to study a soil as though it were a living tissue. Emphasis is given to the changes brought about by the soil *as a whole* under defined experimental conditions, and care is taken that the soil itself is not interfered with throughout the experimental period. The principle is recognized that 'the biological changes taking place in soil are a direct result of the initial chemical stimulus applied to the soil, and are as much a part of the over-all chemical change as the more easily identified metabolic changes themselves' (Lees and Quastel, 1946).

An apparatus is used in the new technique whereby a column of soil (in the form of sieved air-dried crumbs) is perfused with oxygenated or aerated fluid by a circulatory process. This same soil solution is made to percolate through the soil for an indefinite period. The soil perfusate is adequately mixed and aerated and the perfusion is intermittent, so that waterlogging of the soil does not take place. The process is continuous and may be maintained for an indefinite period. The substance whose metabolism is being investigated is dissolved in the perfusion fluid or mixed with the column of soil. Analysis is confined to the constituents of the perfusate, but the soil may be examined after any arbitrary time for analysis of ions adsorbed on it. The apparatus has many advantages for the biochemical study of soil, and with it many aspects of metabolism are as amenable to study in soil as they are in plant or animal tissues. The soil is, in fact, treated as a biological whole, every effort being made to ensure constancy of the environment in which the soil is exercising its metabolic functions.

Experiments with this apparatus confirmed all earlier observations on the biological nature of soil nitrification. Further experiments gave rise to the conclusion that the rate of nitrification of a given quantity of ammonium sulphate is a

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function of the degree to which the ammonium ions are adsorbed on, or combined in, the soil in the form of the soil's base-exchange complexes. The greater the amount of adsorption, the faster is the nitrification. This was shown by comparing the rates of nitrification of soils having different amounts of ammonium ions adsorbed upon them. The only tenable explanation of the results was that the adsorbed ammonium ions are those which are preferentially nitrified by the soil organisms. This led to the prediction that the addition of sterile soils to a nitrifying soil would increase its rate of nitrification in proportion to the base-exchange capacities of the added soil. This prediction was verified.

The interpretation of these results is that the nitrifying bacteria grow on the surfaces of the soil crumbs at the sites where ammonium ions are held in base-exchange combination, and proliferate at the expense of such adsorbed ammonium ions. The rate of proliferation becomes proportional, therefore, to the area of soil surface on which ammonium ions are adsorbed or combined, and is thus a function of the base-exchange capacity of the soil.

The fact that proliferation of the nitrifying organism takes place only at those specific sites of the soil surface where the ammonium ions are adsorbed leads to the conclusion that, when all these sites at the surface have been occupied, further growth of the organisms will not occur except to replace cells which have died and disintegrated. Remarkably few living nitrifying cells enter into the soil solution. This leads to the conception of a bacteria-saturated soil; that is to say, a soil where the area of proliferation is limited and cannot be extended owing to full occupancy of available sites for proliferation. Such a soil may be shown to break down substrates, specific for the organisms which enrich the soil, at constant rates. It does not exhibit the familiar logarithmic course of substrate-breakdown which obtains during proliferation. An important use may be made of such a bacteria-saturated soil. It may be made to yield information as to whether any given substance is broken down by the cells which saturate the soil. If an organic nitrogen compound, for example, is broken down and oxidized to nitrate by nitrifying cells, then the course of nitrate formation in a soil saturated with such cells should be linear, and show no initial lag period. If a lag phase does take place, the inference is that the compound in question needs attack by organisms other than the nitrifiers before nitrification can take place. In this way it has been proved that aliphatic amines, which are nitrified in soil, require organisms other than the nitrifiers to effect the initial decomposition.

An interesting new observation has been that while hydroxylamine, at small concentrations, is toxic to the nitrifying organisms and is apparently not nitrified, the presence of sodium pyruvate secures a speedy nitrification of the amine. Pyruvic oxime also undergoes rapid nitrification by a soil enriched with nitrifying organisms. In view of the hypothesis of Virtanen and Laine that oxalacetic oxime is involved in symbiotic nitrogen fixation, the fact that pyruvic oxime undergoes rapid nitrification may throw light on the mechanism whereby ammonia is oxidized to nitrate in nitrifying cells.

Another phenomenon observed by means of the perfusion apparatus is the remarkable bacteriostatic effect of potassium chlorate on the organisms that convert nitrite to nitrate. Small concentrations of chlorates (e.g. $M/10^6$) have the power of preventing the development of *Nitrobacter*, while that of *Nitrosomonas* proceeds unchecked. The result is that when nitrogenous substances are nitrified in soil in the presence of small quantities of chlorates, nitrites but not nitrates accumulate. Potassium chlorate acts as a typical bacteriostatic agent. It does not poison or interfere with the bacterial oxidation of nitrite to nitrate, for with a bacteria-enriched soil the conversion of nitrite to nitrate proceeds at a constant rate uninfluenced by concentrations of chlorate which inhibit proliferation of the organisms involved. Chlorate bacteriostasis may be neutralized by the presence of nitrates, which appear to act specifically. Explanations of these phenomena are still lacking.

LIBERATION OF FREE NITROGEN

The conditions under which this process takes place are not well understood, but it appears to be agreed that the loss of free nitrogen from the soil is greatly encouraged by poor drainage and lack of aeration. It may, however, be of considerable magnitude in well-managed cropped soils and probably also in lands still in a virgin condition.

Numerous heterotrophic organisms are known to be able to break down nitrates and nitrites with liberation of nitrogen (or oxides of nitrogen), but their quantitative significance in soils has not yet been assessed.

Nitrites react, of course, in acid or slightly acid solution with urea and amines to liberate nitrogen. It is possible, though it seems unlikely, that this chemical mechanism may form a major means by which free nitrogen leaves the soil.

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Book reviews

IDENTIFICATION OF ORGANIC COMPOUNDS

Characterization of Organic Compounds, *by F. Wild. Pp.* 306. *University Press, Cambridge.* 1947. 18*s. net.*

Senior students of organic chemistry and research workers are frequently confronted with the problem of identifying organic compounds and of preparing derivatives of new substances which may serve for their future characterization. This is especially necessary in the case of liquids. Suitable derivatives should be solids with well-defined melting-points, capable of ready preparation in a state of purity. Many methods are well known, but numerous new reagents and procedures have been introduced in recent years, and if a satisfactory derivative is not readily preparable the chemist may spend much time in searching the literature.

This excellent book gives all the important general methods to the end of 1943, with full practical details for the proper preparation of the derivatives and frequently of the reagents themselves. It includes many references to original, mainly recent, papers and tables of melting-points. The arrangement of the book is according to the type of compound to be characterized. The headings include hydrocarbons, halogen and hydroxy compounds, aldehydes, ketones, acids and derivatives, and amines and various other nitrogen-containing compounds. Author and full subject indexes are provided.

The need for such a volume has long been pressing, and Dr Wild's book is destined to find an honoured place on the shelves of all organic laboratories.

W. BAKER

MATHEMATICS IN PHYSICS

Methods of Mathematical Physics, *by Harold Jeffreys and Bertha Swirles Jeffreys. Pp.* $x + 679$. *University Press, Cambridge.* 63*s. net.*

No one is better qualified to write a book on the methods of mathematical physics than the versatile Harold Jeffreys, now Eddington's successor at Cambridge. Here, in collaboration with Mrs. Jeffreys, herself an experienced quantum physicist, he gives a complete account of all the methods used in at least two distinct branches of theoretical physics. The reputation of the authors is in itself sufficient to recommend the book, but if anyone wants to have what is easily the most complete account of the techniques now so commonly employed he cannot possibly do better than get this volume. It is a mammoth book of nearly seven hundred pages, including as two of its chapters the well-known tracts on operational methods and Cartesian tensors, now out of print. It is not everyone's meat, but those who suddenly find themselves needing a particular technique (e.g. complex integration or the use of Fourier integrals) will get what they want here; and as they turn over the pages they will be grateful for a high standard of rigour, no loose statements, and withal a certain racy sense of humour. They will realize the quite astonishing way in which different branches of physics are unified by virtue of the mathematical methods used in discussing them. This is a volume in the best Cambridge 'big blue book' tradition.

C. A. COULSON

ANIMAL HUSBANDRY

The Breeding of Farm Animals, *by Chapman Pincher. Pp.* 149, *with* 7 *plates and* 65 *figures. Penguin Books, London.* 1946. 1*s. net.*

While plant breeding is usually done by experts, the breeding of animals is carried out by the individual farmer. This being so, it is all the more remarkable that few, if any, courses on the science of animal breeding are included in present agricultural courses at colleges and farm institutes. This book, which sets out in simple language the principles of scientific animal breeding, should therefore supply much-needed information. Chapters on genes, Mendelism, dominance, and sex linkage are well illustrated by diagrams which will greatly assist those knowing nothing of the subject.

In the introduction the author points out that in pre-war years the annual value of the edible products of British agriculture was £250,000,000, and that of this total 60 per cent. was contributed by the industry of animal husbandry. Improvements in the efficiency of animal production would therefore be to our material advantage. In a chapter on systems of breeding the uses of inbreeding, out-crossing, and grading-up are discussed, and stress is laid on the necessity for keeping records of the performance of offspring.

J. HAMMOND

AGRICULTURAL BOTANY

Principles of Agricultural Botany, *by Alexander Nelson. Pp. xviii* + 556. *Thomas Nelson & Sons Limited, London.* 1946. 35*s. net.*

The more we live in towns, the greater are our demands on the country: we all realize now that the proper use of the resources of the plant kingdom is a vital necessity. This scientific management of crop plants is a profession still in its infancy but destined for rapid expansion. For the training of recruits to this profession Dr Alexander Nelson has prepared a textbook to stand beside the *Agricultural Botany* of John Percival. In the light of his wide agricultural knowledge and his teaching experience in the University of Edinburgh, Dr Nelson puts mastery of technological details second to a grasp of principles applicable to a diversity of crops.

His first section, of 229 pages, treats of plant morphology and anatomy, furnishing among other illustrative examples five comprehensive tables for the identification of trees in winter, of common legumes, and of grasses. The second section, of 202 pages, describes the principles of plant physiology, concluding with a chapter on pasture. Section 3 introduces in 67 pages the subject of weeds, insect pests, and plant diseases. The volume concludes with a 34-page section on heredity, evolution, and classification.

Judged by wartime standards, the production has an air of refreshing opulence. There are 145 full-page plates, including 17 in colour, and 182 text figures. Almost without exception the illustrations are novel and apposite. The text is set in a well-spaced 11-point fount, and the proof-reading has been efficient.

Dr Nelson's work cannot fail to be appreciated in this country: an allocation of copies would be even more welcome overseas, where there is a pressing need for botanical textbooks with a background of British Commonwealth experience.

R. W. MARSH

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IPATIEFF'S LIFE-STORY

The Life of a Chemist: Memoirs of V. N. Ipatieff, *edited by X. J. Eudin, H. D. Fisher, and H. H. Fisher, translated by V. Haensel and Mrs. R. H. Lusher. Pp. xvi + 658, with 7 plates. Stanford University Press, California; Geoffrey Cumberlege, London.* 1946. 33*s.* 6*d. net.*

Vladimir Nikolaevich Ipatieff is assured of a permanent place among the great Russian chemists. His long career, so full of variety, of light and of shade, has always borne the mark of genius. Born in 1867, Ipatieff achieved distinction in Tsarist Russia. He became Professor Ordinarius at Mikhail Artillery Academy and lecturer in the University of St Petersburg in 1902, and two years later rose to the military rank of colonel. In 1910 he was promoted to major-general, and in 1916 he was elected into the Russian Academy of Sciences. Throughout this period and for twelve years after the Revolution he cultivated with outstanding success and vigour a fruitful field of chemical research, dealing particularly with catalysis at high temperatures and pressures. As an authority on explosives and chemical warfare he became an indispensable figure in Russia during the first world war. Under the early Soviet regime he took a leading and forceful part in the development of Russian chemical industries. For all this work his country owes him a great debt. Ipatieff tells in this book the story of his life in simple and unadorned terms. He describes his scientific work only in bare outline, and fills in the background with a rich and variegated sketch of Russian life and personalities, charged with much detail of historical value. Although he held aloof from politics and tried to do his best for his country, this illustrious chemist found himself obliged in 1930 to leave for ever, as he says, 'my beloved country, my beloved Leningrad, and those laboratories in which I had spent the happiest hours of my life.' Fortunately he was able to continue his scientific work in America, as professor in the Northwestern University and Director of Research to the Universal Oil Products Company.

JOHN READ

PLASTICS FOR INDUSTRY

Plastics for Production, *by Paul I. Smith. Pp.* 216. *Chapman and Hall Limited, London.* 1946. 15*s. net.*

Today we are only too frequently told that we live in an age of plastics, and in many respects this is true. During the last ten years plastics have been playing an increasingly important part as raw materials for modern industry. Where wood or metal or ceramics had previously served we now find plastics doing the job instead.

In certain fields it is inevitable that plastics must supplant these traditional materials. But the real future of plastics lies in their use as new substances in their own right. They are taking their place alongside the established products to provide us with a more versatile and extended range of raw materials.

Unfortunately, plastics are suffering today from a surfeit of publicity, and have been attributed with almost limitless potentialities. Plastics, like other materials, have their limitations: they cannot do everything. In *Plastics for Production* we find what they can do and what they cannot. Paul I. Smith has written this book for the engineer who is looking to plastics for a raw material suitable for his work. All the common plastics are here, and their properties are discussed critically and dispassionately. For anyone in search of information that will enable him to discriminate between the multitude of plastics available to him this book should prove invaluable.

J. G. COOK

DETERMINATION OF HYPER-FINE STRUCTURE

High Resolution Spectroscopy, *by S. Tolansky. Pp.* 291 + 4 *plates. Methuen and Company Limited, London.* 1947. 21*s. net.*

This is a practical account of the techniques rather than the results of high-resolution spectroscopy. A detailed consideration of the theory and performance of the Fabry-Perot and Lummer plate interferometers and of the echelon grating assumes a central position in the book, and occupies about half its length. The writing here, as elsewhere, is clear and authoritative.

A notable section of the book (and one which this reader must confess to have appreciated most) deals with light sources (67 pp.). These chapters contain first-hand, critical accounts of the experimental arrangements used for exciting spectra—the emphasis being, of course, on fine-line atomic excitation—which will prove of great interest, not only to spectroscopists in general but to workers in allied fields. Much of the information given here was previously to be found at best in scattered papers in the literature, and often only as a verbal laboratory tradition. Moreover, in times when the tendency can be discerned for research to become subordinated to apparatus-making, Dr Tolansky's descriptions of simple, elegant devices which work, and which provide answers to crucial experiments, are stimulating. A good book.

R. F. BARROW

PENICILLIN

Penicillin, its Properties, Uses and Preparations. *Pp. vi* + 199. *The Pharmaceutical Press, London.* 1946. 10*s.* 6*d. net.*

The production of penicillin is now so great that in almost all parts of the world the drug is freely available for all who need it remedially, and for research purposes. As a result large numbers of pharmacists, physicians, research workers, and others require to know the best methods of handling it. All the necessary information will be found in this excellent little book published by direction of the Council of the Pharmaceutical Society of Great Britain. Although this is essentially a practical handbook for pharmacists, the compilers have wisely recognized that the intelligent use of penicillin depends upon a general knowledge of all its properties. Consequently an account is given of the history of penicillin, its commercial manufacture, and other aspects of the subject not directly related to its pharmaceutical use. Although these less relevant aspects are necessarily dealt with quite briefly, there is an extensive bibliography for those who wish to read more widely. The sections on legislation relating to penicillin describe British and American practice, but this is similar to that followed in many other countries.

An account is given of the indications for the clinical use of penicillin and of methods of dispensing and storing solutions, ointments, creams, lozenges, and other pharmaceutical preparations containing the drug. There is also a description of the cylinder plate, serial dilution, and other standard methods of assaying penicillin.

This book can be strongly recommended, and if revised from time to time it should remain a standard work for many years.

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ENDEAVOUR

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The conservation of energy

The theory of the Conservation of Energy was the greatest physical generalization of the nineteenth century, and played in the field of physics a part comparable with that of the principle of the Conservation of Matter in the field of chemistry. These two principles, which the study of atomic phenomena has shown to be interdependent, are today of such fundamental importance that it is sometimes difficult to realize that neither is much more than a century old. The present year marks an important centenary in the history of physics, for it was in 1847 that a paper was published in *The Philosophical Magazine* in which James Prescott Joule described in detail his measurement of the mechanical equivalent of heat by the famous paddle-wheel method. This investigation not only showed the precise relationship between heat and mechanical work but pointed the way to the understanding of the quantitative relationship between all forms of energy. A page of Joule's notebook, in which he outlines this historic experiment, is reproduced in Professor H. J. Fleure's article on the Manchester Literary and Philosophical Society—of which Joule was a distinguished member—elsewhere in this issue.

As with so many great scientific discoveries, Joule's work was inspired by that of certain of his predecessors and contemporaries. It was Joule's own genius, however, which first showed conclusively that a variety of observed phenomena relating to energy could be interpreted in terms of a single principle. In some respects he was, indeed, hindered by contemporary thought, for the caloric or materialistic theory of heat, according to which heat had the properties of a fluid, was common physical currency. The dynamic theory of heat, which Joule's work so firmly established, was not generally accepted until well after the middle of the nineteenth century.

The caloric theory had long found indirect support in the phlogiston theory, for until the latter was challenged there was little inducement to question the former, which had much in common with it. Caloric, like phlogiston, was supposed to be a fluid and to possess neither weight nor substance. Originally it was assumed to be highly elastic, and its particles were believed to repel one another. In a later form of the theory, such as that expounded by Marat in 1780, it was assumed that heat particles attracted ordinary matter and that heat became distributed between different bodies in quantities proportional to their mutual attractions. Although erroneous, the caloric theory, like the phlogiston theory, had much to commend it as a valuable working hypothesis. Nicolas Carnot and Lord Kelvin, for example, though ultimately accepting the dynamic theory, laid the foundations of thermodynamics on the basis of the caloric theory.

The caloric theory was first challenged when quantitative methods began to be introduced into the study of heat, just as the phlogiston theory became suspect soon after the balance was accorded importance in chemistry. The introduction of quantitative methods was due in large measure to Joseph Black, who in the latter half of the eighteenth century formulated the concepts of specific and latent heats.

The first categorical refutation of the caloric theory was made by Benjamin Thompson, Count Rumford. Rumford's observations and measurements of the heat generated during the boring of brass cannon, made while he was Minister of War in the Bavarian service, are well known. He made use of Black's methods to show that, contrary to the prediction of the caloric theory, the specific heat of the brass turnings produced while the cannon were being bored was identical with the specific heat of the original brass. His results, summarized in his classic paper 'An Enquiry

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Concerning the Source of the Heat which is Excited by Friction,' were communicated by him to the Royal Society in 1798. It was in this paper that he stated his definite opinion that heat is a form of motion. Rumford's conclusions were confirmed by Davy in 1812, on the basis of observations of the melting of ice by friction. Davy, too, asserted that heat is a form of motion and that its laws are essentially the same as the laws of motion. Five years earlier the versatile physicist and Egyptologist, Thomas Young, had also expressed serious doubt of the truth of the theory of caloric.

It is perhaps not commonly known that although Rumford himself never made a quantitative estimate of the mechanical equivalent of heat, his published results make such an estimate possible. The necessary calculation was in fact made some fifty years later by Joule, who obtained a value of the same order of magnitude as he had himself deduced from his own much more precise experiments.

A calculation of the mechanical equivalent of heat was made by Julius Mayer on the basis of the difference in the work required for the adiabatic and the isothermal compressions of a gas. Mayer published his paper, 'Remarks on the Forces of Inorganic Nature,' in *The Philosophical Magazine* in 1842. Mayer himself always insisted that he had priority over Joule in determining the mechanical equivalent of heat, but the more probable interpretation of the known facts is that they arrived at their conclusions independently and at about the same time.

A clear exposition of the principle of the conservation of energy was published also in 1843 by the Danish philosopher Colding. He observed that when a loaded sledge was drawn along rails made of various materials the ratio of the heat developed to the work done was approximately constant.

Joule's first experiments in this field were made in the latter half of 1840, when he published a note on the heating effect of an electric current. Subsequently he related the heating effect to the mechanical work done in turning the electrical generator, publishing his first calculation of the mechanical equivalent of heat in 1843. In 1845 he made an independent determination by measuring the heat evolved during the compression of a gas. Later in the same year he described the method, elaborated in his paper of 1847, for measuring the mechanical equivalent of heat by rotating a paddle in a vessel containing water or other liquid. His researches in this field were summarized in the celebrated memoir which he presented to the Royal Society in 1849.

In a letter to Pictet in 1804, Rumford expressed the hope that his observations on the generation of heat during the boring of cannon would give him, within his own lifetime, the satisfaction of 'seeing caloric interred with phlogiston in the same tomb.' His hope was disappointed, and it was Joule's work which was primarily responsible for bringing about this result. Even as late as 1856, however, some standard works of reference gave precedence to the caloric theory—a good illustration of the difficulty the pioneer so often meets in gaining general acceptance of new ideas, no matter how well substantiated they may be.

The determination of the mechanical equivalent of heat did far more than provide a very important physical constant. The fact that it was a constant, by whatever method determined, established the general principle of the conservation of energy, in the full enunciation of which much was owed to Helmholtz in Germany and Colding in Denmark. The progress of science does not consist merely in the unceasing collection of new facts, indispensable though this process is, but in the interpretation of these facts in terms of a relatively small number of general principles. Joule's work, inspired by the work of those who preceded him, is of particular note because it fell to him, as it does to very few, to establish one of those principles the discovery of which marks a well-defined stage in the advance of science.

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X-rays and the carbon atom

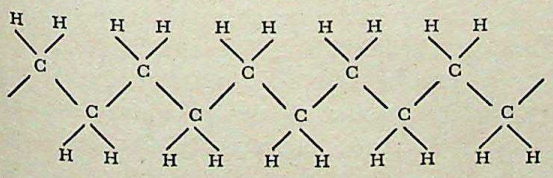
KATHLEEN LONSDALE

Life itself, as well as a wide range of human activities, depends upon the properties of carbon atoms, which are unique in the extent of their ability of linking together to form complicated molecules. In recent years X-rays have proved a valuable supplement to classical methods of studying the architecture of complex substances, and have provided information about the shapes of molecules and interatomic distances, especially in the case of organic compounds, which is obtainable in no other way.

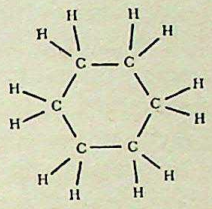
The carbon atom occupies a unique place in the periodic table of the elements. It is neither electropositive like the metals nor electronegative like the halogens, although on occasion it can behave like either. In forming compounds it prefers neither to surrender nor to accept electrons, but to share them with other atoms. It can combine with elements of widely differing properties. With other carbon atoms it can combine to an unlimited extent.

Carbon, being quadrivalent, has four outer electrons to share, and chemists have long believed that when it forms four single covalent bonds, as in methane (CH_4), its valencies are tetrahedrally directed. In carbon tetrachloride (CCl_4), carbon is combined by single covalent bonds with four chlorine atoms tetrahedrally disposed about it. In chloroform ($CHCl_3$), however, the tetrahedron is a little flattened, and the chlorine atoms are a little farther apart than in CCl_4.

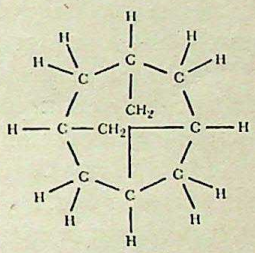
One of the carbon valencies can be used, as in ethane ($H_3C.CH_3$), to form a bond with another carbon atom. By an extension of this process carbon atoms can form long, open chains fringed by hydrogen atoms, or closed chains of various kinds. Examples of open-chain molecules are provided by the paraffins, the fatty acids, and the alcohols. Perhaps the most striking of the carbon-chain molecules is that of polythene (*below*), in which many thousands of atoms are linked together, forming a substance of unique electrical and mechanical properties.



By way of contrast with the relatively infinite molecule of polythene there are such finite, closed molecules as those of cyclohexane:

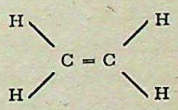


and adamantine:



In all these carbon compounds there are only single bonds between the carbon atoms.

Carbon may, however, also form double bonds, as in ethylene



or in carbon dioxide (O=C=O), the substance which contributes more than any other towards which perhaps contributes more than any other towards linking chemistry with the sciences dealing with living matter.

Carbon can form triple bonds, as in acetylene (H—C≡C—H) or hydrocyanic acid (H—C≡N), but it does not form quadruple bonds. There is no finite molecule Si≡C or C≡C. When carbon combines with carbon only, it forms infinite molecules. But it can do this in more than one way. Diamond is essentially pure carbon, and so is graphite (although both are usually somewhat impure), and yet they are very different. Pure diamond is colourless and hard, and has a very low electrical conductance and low diamagnetic susceptibility. Its density is about 3·5 gm.

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per c.c. Graphite is black and soft, and has high electrical conductivity and large diamagnetic susceptibility. Its density is only 2·3 gm. per c.c. These differences can result only from the way in which the atoms are joined together, that is, from the *structure*. Both are scientifically interesting and industrially important, but both of them still present some unsolved problems.

How can we determine a structure composed of atoms which are themselves only about 0·015 millionth of a centimetre (1·5 A) apart? The answer is that we can do so only if there is some regularity in the atomic arrangement, if it repeats in space so as to form a *pattern*. All solid substances are, in fact, crystalline; that is, they are built up as a regularly repeating three-dimensional atomic pattern. The arrangement of the pattern on a wallpaper or a honeycomb can be seen directly. If the pattern we want to see is too small to be distinguished with the naked eye, we look at it with a microscope. In either case we are using light-waves. But we cannot distinguish two objects separately unless the distance between them is at least one-third of the wavelength of the light we are using, that is, at least 1,500 A, and the distance between the carbon atoms in diamond is only one-thousandth of this value. An electron microscope, used in conjunction with special techniques for the preparation of specimens, will resolve down to as little as 15 A, but this is still too gross to show us the detail of the diamond or graphite patterns. It so happens, however, that the wavelengths of X-rays are of the same order of size as the distances between the atoms, and they will also affect a photographic film in just the same way as do light-waves or electrons. We cannot use X-rays to see the atoms in the crystal directly, but the regular atomic arrangements can scatter the X-rays in such a way as to give regular diffraction patterns, which can be recorded photographically. The atoms of a liquid or a gas will also scatter X-rays, but they do not give a pattern because they are not regularly arranged. They give no more than diffuse rings from which the *average* distance apart of the atoms can be calculated. The X-ray diffraction patterns given by solids are sometimes quite beautiful, but their interest to the scientist lies in the fact that they can be used to deduce the exact arrangement of the atoms, and even to tell us the distribution of electron density in and between the atoms. This cannot be done directly. It involves a good deal of mathematical calculation, although some aspects of the atomic pattern, for instance its symmetry, can often be found by inspection. The diffraction pattern obtained depends not only on the substance examined and the kind of X-rays used, but on the particular experimental technique adopted. Some typical patterns for carbon compounds are shown in the accompanying illustrations.

Such measurements show that in diamond there is tetrahedral symmetry, each carbon atom being tetrahedrally attached to four others by single bonds, thus building up one large three-dimensional molecule, which is very hard and has a very high melting-point because of the strength of the covalent bonds between the atoms. There are no weak links in the chain. In fact, diamond never does melt: it is either converted into graphite or it sublimes. The hardness of the diamond is its most important industrial property: of all the diamonds now mined, about 80 per cent. by weight are used for industrial purposes and eventually destroyed. Owing to its structure diamond is an excellent conductor of heat but has a very small coefficient of expansion. Glass, because of its low thermal conductivity and large coefficient of expansion, cracks even when it is put into boiling water, but diamond can be brought to a bright red heat and plunged into liquid air without any harmful effects. This also is most important industrially, because diamonds used in high-speed engineering tools get very hot and must not crack or wear away too rapidly. With suitably shaped holes drilled through them, diamond dies are used for drawing the extremely fine tungsten wires needed for electric lamps and valves. A rod of tungsten 6 ft. in length and as thick as a pencil will yield a thousand miles of such superfine filament, finer even than a spider's thread. Diamonds are used in machine tools, and in drills which can penetrate the earth's surface to depths of over 10,000 ft. The famous Simplon tunnel, opened in 1906, was the first major engineering project in which the diamond drill was employed, and it has since been used in many mining and engineering enterprises. The high refraction and dispersion of light-waves, which give diamonds of gem quality their sparkle and fire, are also due to the structure of the crystal.

The structure of graphite is quite different. The carbon atoms no longer have tetrahedral symmetry, and the bonds between them are not single bonds; nor, however, can they be double bonds, for each atom is linked up with *three* others to form a plane hexagonal network. Since the four carbon valencies are shared between three bonds, the order of each bond must be 4/3. Graphite

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consists of such hexagonal sheets of atoms piled together to form a layer structure, with very weak forces between the layers. It is this layer structure, with very strong forces between the carbon atoms in the planes and very weak forces between the planes, that gives graphite its peculiar properties. Since the layers slip easily on one another, graphite is an excellent lubricant. Graphite layers are put on to the paper when we write with a 'lead' pencil, or on to the stove when we polish it with 'black lead.' The same process occurs when we use carbon paper, and Indian ink is finely ground graphite baked up with a glutinous base. Since the graphite layers are so loosely held together it is possible to push many different kinds of atoms between them. This explains the fact that the rather impure forms of carbon obtained when carbonaceous matter is burnt have the power of absorbing gases and of removing colouring matter from solution. They are used, for instance, to make sugar white for table use.

X-ray photographs can give not only the structure of a crystalline substance but a measure of the size of the little crystallites of which it may be composed. Such photographs of various carbons show that they are really just graphite, but in a very finely divided state. It is, in fact, the smallness of the crystallite size that makes them absorb gases so easily. There is more surface for a given volume, and therefore more easy entrance for the gas atoms. X-rays, however, give one more piece of information besides structure and size of crystallites. They tell us how the atoms are vibrating; for the atoms in a solid are not stationary, they are constantly moving to and fro about their mean positions, and in structures such as graphite X-rays show that they move more easily perpendicular to the layers than within them. This fact explains why the absorption of gases by charcoal is so greatly increased at very low temperatures. The atomic vibration, which is of thermal origin, is much less at liquid air temperatures, and the gas atoms can penetrate the layers more easily when the carbon atoms are relatively still. The use of charcoal to absorb the last trace of gas allows double-walled metal containers to be used for the storage of liquid oxygen, hydrogen, and helium. Graphite also has most useful electrical properties. The excess of valency electrons in the layers tends to make graphite behave like a metal; it has quite a high electrical conductance in the layers, although perpendicular to them it is an insulator. In the form of gas carbon, etc., the graphite layers are orientated in all directions and the substance as a whole conducts, although pressure, by altering the orientation, will alter the resistance. The rods of arc lamps are made of fairly pure carbon, and so are dynamo brushes. Carbon is used in telephone transmitters because of the variation of its resistance with pressure, and carbon was also used in the earlier filament lamps, some of which were most ingenious. It is interesting to recall that in designing them Edison experimented with over six thousand sorts of vegetable fibres collected from all over the world.

Even yet, however, we have much to learn about the structure of diamond and of graphite. X-rays can give a very accurate measurement of the distance between the carbon atoms in diamond. The distance varies from 1·54465 A to 1·54443 A in different diamonds so far investigated. This does not seem a very large variation, but it is a real one; the possible error in any one measurement is only $\pm$ 0·00002 A. These differences are doubtless due to the presence of impurity. Spectroscopic examination has shown that traces of aluminium, silicon, calcium, and magnesium are present in all diamonds examined, and other, heavy, elements are present in some, but the method used could not have detected the presence of hydrogen, boron, nitrogen, oxygen, or other light elements, some of which are quite probable impurities. We do not know, however, how the impurity enters into the diamond lattice in such a way as to expand or contract it as a whole, which is what the X-ray results indicate. Then again, there are some effects on X-ray photographs which have not been explained at all. We do not know what causes the little triangles of spots seen near the centre of figure 1, though we do know that one triangle is given by Cu$K\alpha$ and the other by Cu$K\beta$ radiation (the two main wavelengths found in the X-rays from a copper target). Not all diamonds give these triangles, although most do; in some diamonds they are completely missing. They are what is known as a structure-sensitive effect, but they are not temperature-sensitive to any noticeable extent. The two kinds of diamond—those that give this X-ray effect and those that do not—differ also in other ways, although they apparently have the same structure. Their absorption of infra-red and ultra-violet radiation differs. Whereas diamonds of the type that do not give the triangle effect give an excellent divergent beam X-ray photograph of the kind shown in figure 7, those that give the effect most strongly give no divergent beam pattern at all. Sir C. V. Raman has suggested

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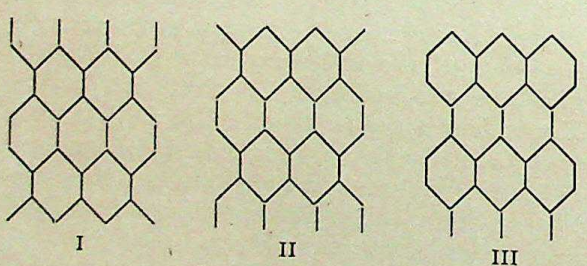
that there are really four kinds of diamond, varying in the orientation of the tetrahedral carbon atoms.

One most intriguing fact about diamond is that although Nature has made so many, man does not yet know how to make diamonds in the laboratory. Graphite is the more stable form of carbon, and diamond can be converted to graphite, but we have not yet learned to reverse this process. It is true that some small specimens in the Natural History Museum at South Kensington, labelled as having been made by J. B. Hannay and presented to the Museum in 1880, have been proved by X-ray analysis to be real diamonds. It may be that Hannay did in fact make them; there is no valid reason for believing that he did not except that no one has yet succeeded in repeating the experiment. Hannay himself claimed only some 6 per cent. of successes in his numerous attempts.

Graphite also presents its problems. The distance between the carbon atoms in the layers, which are more strongly bound together than those in diamond, is only 1·4210 ± 0·0001 A. The layers themselves are 3·3541 A apart at 15° C. As the temperature rises, the distance between the layers increases, the average value of the coefficient of expansion over the temperature range 14·6–800° C being $28{\cdot}3 \times 10^{-6}$. The carbon-to-carbon distance in the layers, however, actually contracts at first and only begins to expand above 400° C. The average coefficient of expansion from 0 to 150° C is $-1{\cdot}5 \times 10^{-6}$, and from 600 to 800° C it is $+0{\cdot}9 \times 10^{-6}$.

Consecutive layers of atoms in graphite do not lie vertically over one another. Most graphite



consists of alternate layers such as I, II; I, II; . . ., but some graphite takes the form I, II, III; I, II, III; . . ., and a small percentage consists of layers randomly arranged. The curious thing is that natural graphites from different parts of the world, and even artificial graphites, seem to have a fairly uniform 80 per cent. of the I, II; I, II structure and 14 per cent. of the I, II, III; I, II, III structure. Faint lines on the graphite powder photographs, as yet unexplained, indicate the presence of further structures. Graphite can also form addition compounds with atoms such as potassium or radicals such as SO_4, which fit between the layers in a regular way; here again a wide variety of arrangement of the graphite layers seems to be possible.

When carbon is mixed or combined with other elements it yields products of great industrial importance. Tungsten carbide is comparable in hardness with diamond, and we are very familiar indeed with the effects of adding small quantities of carbon to iron. Cast iron, which contains upwards of 1·5 per cent. of carbon in graphite form, is very brittle, but it is cheap, readily melted and cast into any desired shape, and is strong in compression. It is used for purposes where cheapness is important and high resistance to shear unnecessary: for lamp-posts and guttering, for example. The range of steels includes very soft steels, mild steels, and medium grades. All these contain less than 1·5 per cent. of carbon; they owe their varying characters almost entirely to the way in which, through suitable heat-treatment, the carbon atoms can be made to fit themselves into the iron framework. The effects both of heat-treatment and of mechanical treatment can be followed by means of X-ray photographs.

From the purely scientific point of view it is of great interest to know how the structures of the various carbon compounds are related to those of diamond and graphite, since these are so different from one another. Generally speaking, the carbon compounds can be divided into two broad groups. There are the aliphatic compounds, in which the carbon–carbon bonds are single; and there are the aromatic and conjugated compounds, in which, as formulated at least, there are both single and double bonds, occurring alternately. The aliphatic compounds include both open and closed chains; the closed chains may be composed entirely of carbon atoms, as in cyclohexane, or the chain may include oxygen or other atoms. In all the aliphatic compounds the carbon–carbon bonds are similar, from a structural point of view, to those in diamond. They are about 1·54 A in length, and bonds from the same carbon atom are tetrahedrally disposed. But there is one significant difference. In diamond the whole crystal is one big molecule and all the bonds are equally strong. In the aliphatic compounds the molecules are of finite size (even in polythene they are 'infinite' in one direction only) and the forces

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IGURE 1 – *Laue photograph of stationary single crystal of diamond, ing the X-rays from a copper target, recorded on a plane film. ote the two little triangles of spots on each side of the central Laue flection. The origin of these is not understood.*

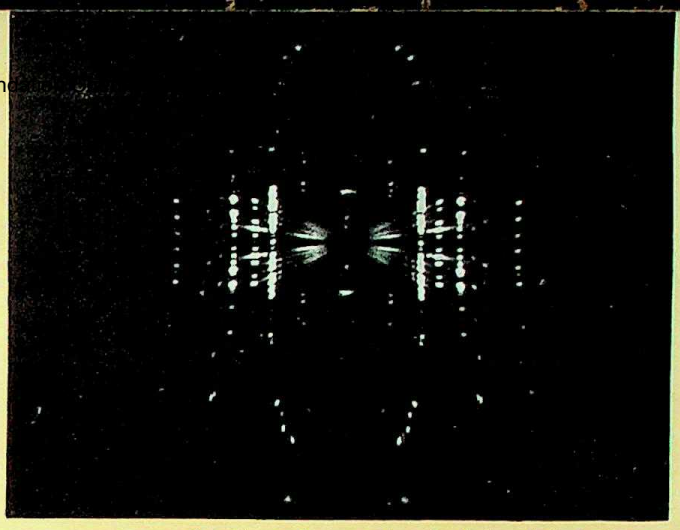

FIGURE 2 – *Rotation photograph of diphenyl butadiene* $(C_6H_5.(CH)_4.C_6H_5)$. *CuK radiation; plane film.*

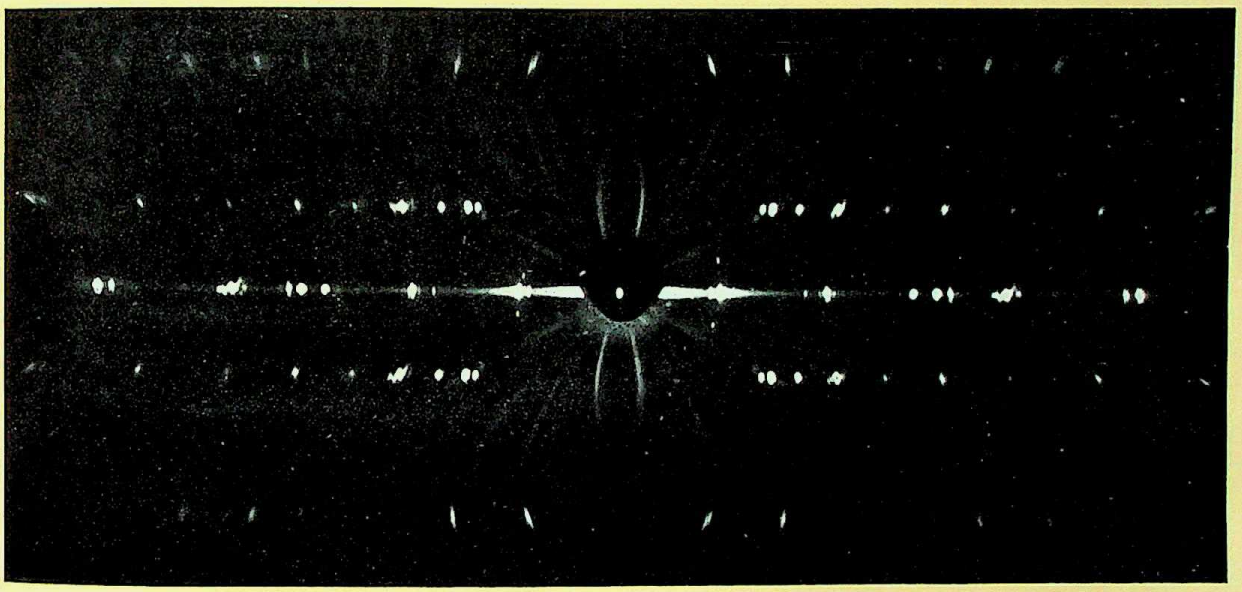

FIGURE 3 – *Rotation photograph of single crystal of graphite, using filtered CuK*α *radiation and a cylindrical film.*

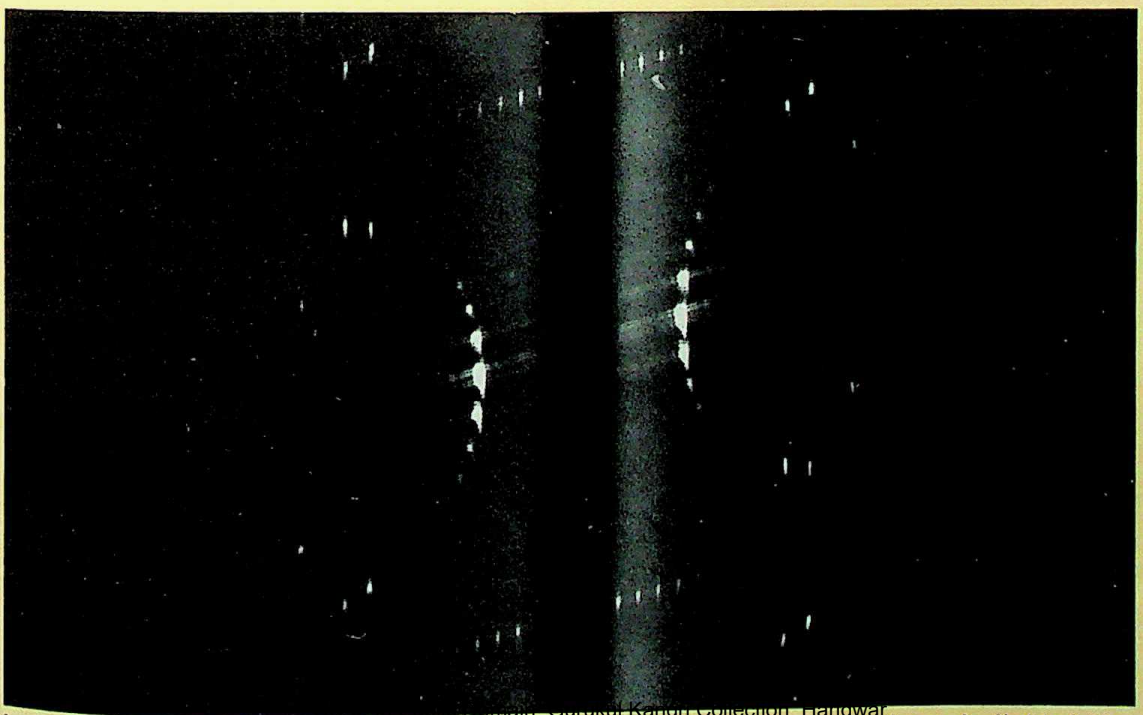

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FIGURE 4 – *Weissenberg photograph of the long-chain paraffin* $C_{18}H_{38}$. *Crystal rotating and cylindrical film moving synchronously to and fro.*

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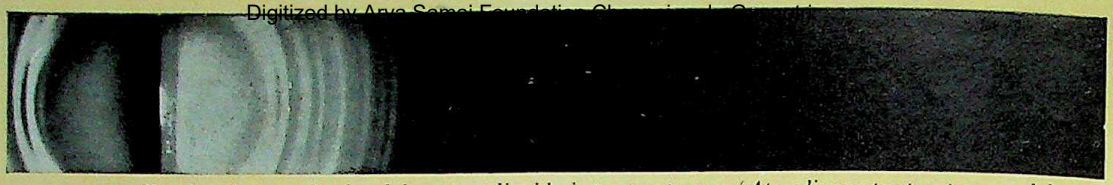

FIGURE 5 – *Powder photograph of cyclohexane at liquid air temperatures. (At ordinary temperatures cyclohexane is a liquid, without a regular arrangement of molecules.)*

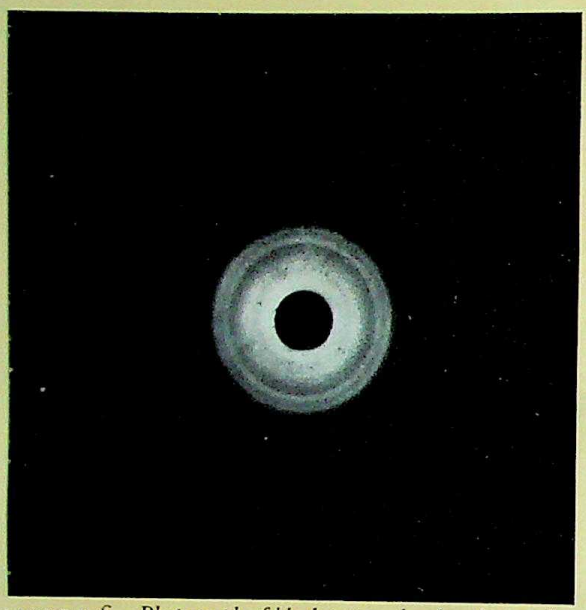

FIGURE 6 – *Photograph of black paper, showing the powder rings of cellulose.*

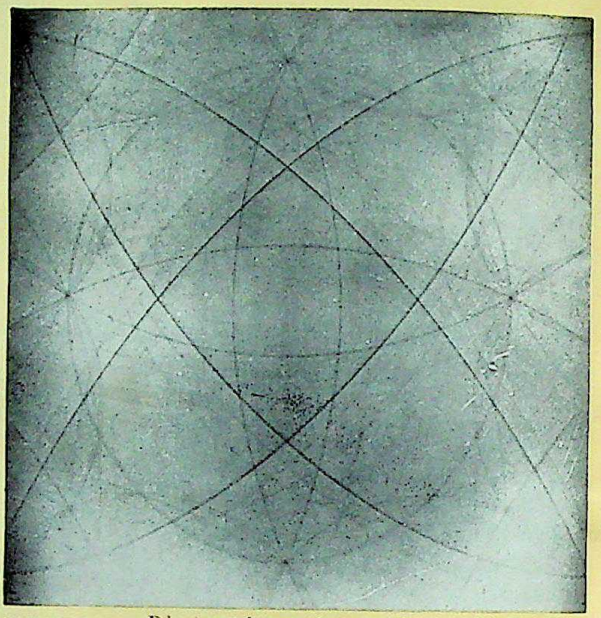

FIGURE 7 – *Divergent beam photograph of a single crystal of diamond. Such photographs, if taken at long distances, can be used to give very accurate measurements of the carbon–carbon distance in individual diamonds.*

between the molecules are weak; in pure hydrocarbons they are as weak as those between the layers in graphite. The distances between the molecules are also of the same order as in graphite, about 3·5 A. If the molecules contain oxygen or nitrogen, the linkages between molecules may be formed by hydrogen atoms. The length of a hydrogen or a hydroxyl bond is 2·5–2·9 A, much longer than the single carbon–carbon bond but not so long as the 3·5 A of the so-called 'van der Waals' bond in graphite. The only carbon compound which is similar in structure to diamond is carborundum (SiC), although even carborundum differs from diamond in also having several alternative structures, in all of which the crystal is one giant molecule. Carborundum, though not so hard as diamond, is nevertheless very hard indeed and is used as an abrasive. Aliphatic compounds, on the other hand, are soft and have low melting-points, because it is so easy to break the bonds between the molecules.

It is a curious fact that even very long aliphatic chains tend to lie parallel to one another, like matches in a box. This is the reason for the formation of soap-bubbles, which are composed of chains of carbon atoms, fringed by hydrogen atoms, standing side by side perpendicular to the bubble surface. The fatty acids, such as stearic, palmitic, and oleic, are essential constituents of oils, fats, waxes, and soaps. These long-chain compounds have a very active group, such as —COONa in the case of soaps, at one end of the chain. When a layer of oil spreads over the surface of water, the active groups fasten themselves tightly to the water surface, while the carbon chains to which they are attached stand up like the pile of of a carpet, holding tightly to each other side by side. The long chains of polythene do not form parallel bundles over the whole of their length, but one molecule will form part of several crystallites, the regions between crystallites being disordered and the crystallites themselves radiating from centres; it is possible, however, to cold-draw polythene so that the crystallites become aligned.

Owing to the tetrahedral arrangement of the single carbon bonds, the carbon rings in cyclohexane and in the sugars are of a zigzag formation, but the rings in aromatic compounds such as

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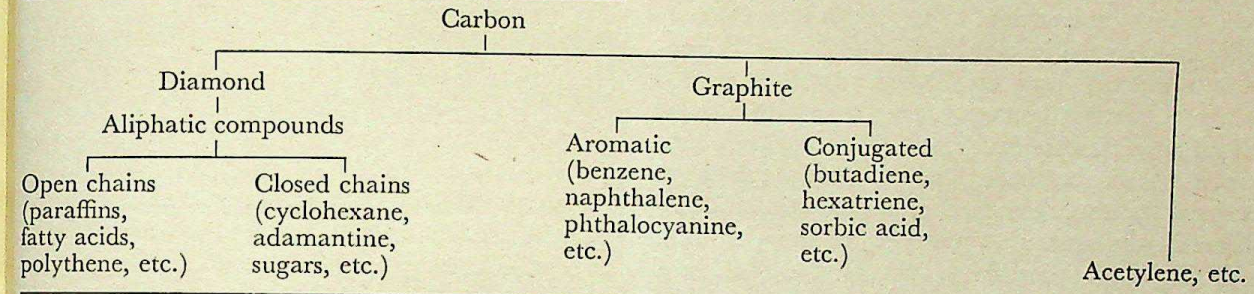
benzene, naphthalene, anthracene, toluene, and so on are quite plane, and the carbon–carbon distance is only about 1·39 A. In these compounds the carbon–carbon bond is intermediate between a single and a double bond, as it is in graphite, and in many respects the condensed benzene derivatives resemble graphite quite closely. If placed in a magnetic field and free to move, they will turn sharply, as graphite does, so that the lines of force lie as nearly as possible parallel to the planes of the molecules. The distance between neighbouring molecules is again about 3·5 A, except where the connection is made by means of hydrogen or hydroxyl bonds. The very large closed ring of carbon and nitrogen atoms which, with its four attached benzene rings, forms the phthalocyanine nucleus, is also aromatic in nature, and electron density determinations by means of X-ray analysis show that the whole molecule is quite flat. In fact, it is so determined to be flat that metals placed in the centre of the nucleus are obliged to form plane bonds to fit on to it, even when they are elements, such as beryllium, which would usually be tetrahedrally co-ordinated. Copper phthalocyanine is the dye known commercially as 'Monastral Blue,' a dye which is normally quite unchanged by light, heat, or chemical action.

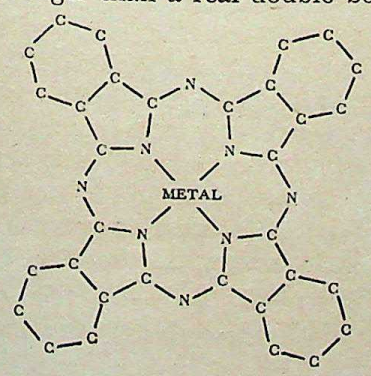
In conjugated compounds, such as butadiene ($H_2C=CH—CH=CH_2$) or sorbic acid ($H_3C—CH=CH—CH=CH—COOH$), where there is an open-chain formation of double and single bonds, X-ray measurements show that there is a tendency for the bonds to equalize. The 'double' bond is definitely longer than a real double bond should be, and again the molecule tries to be flat. In fact, it is flat unless prevented from being so by large substituent groups which get in each other's way. Again, the crystal will try to turn in a magnetic field so that the molecular planes are parallel to the field. This behaviour in a magnetic field shows that there are some electrons (those same electrons which give graphite its semi-metallic properties) which can wander over, or are shared by, all the carbon atoms in the molecule.

The relationships between the structures of the simple carbon compounds can be shown diagrammatically as follows:



There is one group of substances, however, which it is difficult to allocate to any of these divisions: this is the rubbers. Rubber is essentially a high polymer of isoprene $\left(\begin{matrix}H_2C=C—CH=CH_2\\ \quad\quad|\\ \quad\quad CH_3\end{matrix}\right)$. The tendency of the double and single bonds to equalize means that each partakes to a certain extent of the nature of the other, and it is not difficult for the bonds to swing over so that polymerization follows. $\left(\begin{matrix}H_2C=C—CH=CH_2\\ \quad\quad|\\ \quad\quad CH_3\end{matrix}\right)$ becomes $\left(\begin{matrix}—CH_2—C=CH—CH_2—\\ \quad\quad\quad|\\ \quad\quad\quad CH_3\end{matrix}\right)_n$ and in the polymer there is then a 3 : 1 sequence of single and double bonds.

Rubbery chains, of which this is one, tend not to align themselves side by side as the long-chain paraffins do, but rather to curl up, forming a structure which has no definite pattern in space and which gives X-ray photographs similar to those of liquids. Fully stretched, however, rubbers give X-ray photographs similar to those of single rotating crystals. The chains not only become straightened out in the stretching process, but when straight their sideways linkages show regularity over a considerable number of molecules. X-ray examination of simple carbon compounds in which there are three single bonds between two double bonds has shown a further surprising fact,



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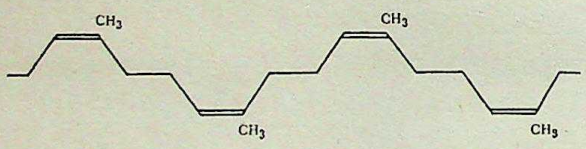
which is that the middle bond of the three is shorter than a single bond ought to be. The chain apparently tries to acquire some degree of conjugation, though why it does so we do not yet know.

Many other high polymers are similar to rubber mechanically.

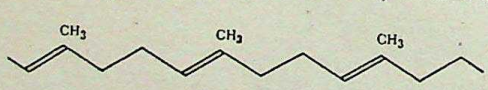
Isobutylene $\begin{pmatrix} CH_3 \\ CH_3 \end{pmatrix} C=CH_2$

polymerizes to polyisobutylene $\begin{pmatrix} CH_3 \\ CH_3 \end{pmatrix} C-CH_2-$

and although the bonds are now all single bonds the chains do not tend to lie out in straight bundles as they do in polythene $(-CH_2-CH_2-)_n$; they curl up, and on X-ray examination give only a pattern corresponding to amorphous or liquid substances. Stretched a thousandfold, however, polyisobutylene gives a beautiful single crystal pattern. The rubberiness of rubber, therefore, is not a peculiar property of the 3 : 1 ratio of single and double bonds. Indeed, there is another form of polyisoprene, gutta-percha, which is not rubbery at all, but is a horny crystalline substance. X-ray studies indicate that rubber is the so-called *cis*-form, which when stretched gives a chain of this type:

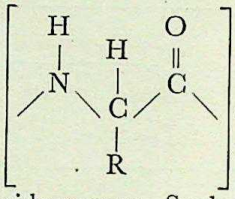


while gutta-percha is the *trans*-form, of the type:



The most important carbon compounds of all, however, are those that occur in living matter, whether of vegetable or of animal origin. In the presence of sunlight, green plants can assimilate the carbon dioxide of the atmosphere and, with water, can build up carbohydrates, which then form polysaccharide chains, of which the best known is cellulose. Vegetable fibres such as cotton and hemp, and the regenerated forms of cellulose fibres such as the artificial silk 'viscose,' give excellent X-ray pictures. These pictures show that the polysaccharide chains must be fully extended, since they give a regular pattern. There are, however, many ways of arranging the same number of carbon, hydrogen, and oxygen atoms. Cellulose is only one way; the alginic acid occurring in seaweeds is another, and this also can be used to make an artificial silk yarn. In fibres the crystallites are all arranged with their lengths parallel or nearly parallel to the fibre axis. (In the case of cotton they are spiralled about it.) In paper or Cellophane, however, they are disarranged, as the X-ray patterns clearly show; paper gives a typical 'powder' pattern (figure 6).

Animals cannot assimilate carbon dioxide, but they need carbon in order to build up proteins, which can be broken down and rebuilt as required. Protein chains are not pure carbon chains; nitrogen is an essential constituent. They are polypeptide chains, built up by the combination of amino-acid residues such as



, where R represents different side-groups. Such chains can exist in almost infinite variety. The protein of natural silk, fibroin, gives a good X-ray pattern, showing the existence of fully extended chains. The patterns given by wool, horn, and hair on the one hand, and muscle on the other, are not so good; but they are curiously alike, showing that in spite of their different chemical constitutions wool and muscle must be architecturally similar. Each gives a typical pattern when unstretched and a different pattern when stretched, but in both states the two substances are structurally alike. X-rays have shown that the protein structures of birds and of reptiles are related. Synthetic fibres such as nylon also give excellent patterns.

Some of the patterns given by the globular proteins such as insulin and haemoglobin, and by the viruses, are so elaborate and so full of information that they are almost more than the present analytical technique can deal with. The recent complete analyses of cholesteryl iodide and of penicillin, however, by the X-ray method used at its highest power, encourage us to think that these other carbon compounds will also, one day, yield up the secrets of their structures.

There remains one field in which X-ray methods have proved disappointing. Many synthetic plastics, although highly polymerized carbon compounds, appear to possess little or no regularity of structure, and therefore give little information in the form of X-ray diffraction patterns. There is, however, still much to be done before we fully understand the structure of the chains, rings, webs, and frameworks of carbon atoms that occur in the simpler compounds.

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The Manchester Literary and Philosophical Society

H. J. FLEURE

The great influence of science upon the development of religious beliefs has been frequently discussed, but the reverse process, the influence of religion upon the development of science, has not always received the same attention. This latter process is, however, a by no means negligible one. The formation of the Manchester Literary and Philosophical Society, one of the oldest British scientific societies, was, as the author here shows, due in some measure to the attempt made in 1662 to establish uniformity of religious belief throughout Britain.

It was especially in the seventeenth century that thinking men first realized that truth may, indeed must, be sought by observation and experiment, that even Aristotle was not a final authority. This momentous realization, in an era dominated by hardened dogma—with persecution an attendant commonplace—drew inquirers together into groups for exchange of thought and mutual encouragement. After the time of Bacon, Gilbert, and Harvey, the outstanding example in Britain is the group which in due course became the nucleus of the Royal Society. The society received its charter from King Charles II in 1662. In some other countries, academies were called into existence by the State and became in considerable measure State institutions. It is characteristic of the British tradition that this movement was, and remained, separate from the organization of the State, however much the State might at times confide various inquiries to the society. In 1662 the Act of Uniformity, which aimed at the establishment of a definite standard of belief and practice in the Episcopal Established Church, came into force. A number of clergy were in consequence ejected from their livings, a notable instance being John Chorlton of Manchester parish church (now the cathedral). He, like many another ejected minister, formed a dissenting congregation which was on the whole less liable to persecution in a place that was not a chartered borough. Birmingham and Manchester were not boroughs, and they developed strong and thoughtful dissenting groups to such an extent that at the end of the nineteenth century it was said that the greater part of the intellectual life of south Lancashire and of Birmingham was associated with Unitarianism and the Society of Friends.

The dissenting groups of the seventeenth century were deeply interested in Calvinistic theology and its philosophical background. They were thus in a sense the continuation of medieval scholasticism outside the more formally authoritarian churches. When toleration developed a little further after the revolution of 1688, John Chorlton's group built Cross Street Chapel, Manchester (1694), as a Presbyterian institution, and Chorlton had Henry Newcome as assistant pastor. As the historic universities and grammar schools were, and long remained, exclusively episcopalian, the dissenting groups were driven to think of education outside the barriers, and were thus impelled towards at least nominal freedom of conscience and, consequently, of discussion. In 1699 Chorlton and Newcome 'set up teaching university learning in a great house in Deansgate,' Manchester, with a five-year course in Arts and Theology. This was an early academy, but not the earliest, as Henry Newcome himself had been educated under Richard Frankland at Rothmell Academy.

The students of this early Manchester Academy were taught by Chorlton and Newcome and used Cheetham's library. After Chorlton's death, another dissenting minister, James Coningham, became a teacher, but with the rise of Tory policy under Queen Anne he had to face threats of prosecution for 'keeping a public academy.' He moved to London in 1712, with the result that the Manchester Academy ceased to function.

The historian of the school and academy at Carmarthen, Professor R. T. Jenkins,[1] described the special features which characterized the eighteenth-century education in the academies:

1. The great prominence given to mathematics and science.

[1] R. T. Jenkins, *History of Carmarthen*, edited by Professor Sir John Edward Lloyd, vol. ii, p. 237 (1939).

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2. The inclusion in the philosophy course of systems which had not yet secured entry into Oxford, such as those of Locke and of the Scottish philosophers.
3. The requirement of a high standard of Hebrew for ministerial candidates.
4. The use of English in place of Latin as the vehicle of instruction.

A very important academy founded at Warrington in 1757 lasted until about 1783. This academy seems to have derived prestige from the fact that Joseph Priestley, who had been minister at Cross Street, Manchester, taught at Warrington (1761–7) before moving to Leeds. Among his pupils was Thomas Percival, founder of the Manchester Literary and Philosophical Society (1781) and of the second Manchester Academy (1786), which replaced the defunct Warrington institution. Percival, who was born in 1740, came of a Warrington medical family. The affluence of the family permitted his travelling on the Continent and attending universities there. His educated and attractive personality secured for him election into the Royal Society of London at the early age of 25. He seems to have been distinguished rather for his general wisdom and dignity than for any outstanding originality in investigation or any special power of exposition.

The dissenting groups and the academies in the eighteenth century were in a special sense discussion groups. Among them there appeared the usual cleavage between the more liberal and the more authoritarian type of mind. The former tended towards Unitarianism, or, as it was sometimes called, non-subscribing Presbyterianism. The authoritarians tended to react against the Unitarian doctrine, and we find Calvinistic and Arminian groups emphasizing the doctrine of the Trinity.

These trends in controversy made the academies, and other schools based on freedom of conscience, more particularly Unitarian; and Cross Street Chapel became Unitarian in fact, although it retained the Presbyterian name. Percival, as a loyal disciple of Priestley, was a leading figure in this development. After he had left Warrington, Priestley spent a year at Leeds (1767–8) and then went to Birmingham, where a 'Lunar Society' was formed, deriving its name from the fact that it met on nights of full moon. The Lunar Society was paralleled by groups in other towns such as Bristol, Dublin, Edinburgh, and Norwich, but the original society had exceptional strength, as it included Erasmus Darwin, Boulton, Watt, Priestley, and Wedgwood. It has been said that it was too strong to last, and; as these famous thinkers died or moved away, the Lunar Society disappeared. We gather that an informal group met in Manchester for some years at Percival's house in King Street, and that his friend and fellow-disciple of Priestley, Thomas Barnes, minister of Cross Street Chapel, was an active member of the group. Hints of their activities are vouchsafed through Percival's proposal for more accurate and comprehensive Bills of Mortality in Manchester (1773), and by his interest in proposals for more comprehensive and accurate parish registers. These efforts of Percival led to the formation of the Manchester Board of Health in 1796.

In 1781, the group around Percival formed themselves into the Manchester Literary and Philosophical Society, with Peter Mainwaring, M.D., and James Massey, Borough Reeve of Salford, as Joint Presidents. The earliest meetings of the society were held at the Assembly Coffee House, but, before the end of 1781, the chapel room of Cross Street was the established place of meetings. Percival, who is reputed to have been one of the first medical men to use cod-liver oil in cases of threatened tuberculosis, succeeded Mainwaring in 1782, and held the Presidency alone from 1789 until his death in 1804. That the new society was influential we gather from the fact that when, in 1786, an academy was founded or refounded in Manchester to do the work previously carried on at Warrington, it was decided that, as a mark of respect, the then officers of the society should be appointed governors.

The papers discussed at the society's meetings were very varied, but we note one by Charles White on gradations in animal forms. He noticed the evidence of such gradation, but refused to consider any idea of evolutionary development. Dr Aikin discussed 'Living in High Latitudes' and elucidated the factors of scurvy. Alexander McDougall wrote on the use of carbolic acid in the curing of wounds. When Priestley's sympathy with the French revolution led a Birmingham mob to burn his house in 1791, several members of the society wished to send him a friendly message, and Edmund Burke in Parliament denounced the sympathy of Manchester with the Jacobins. There was evidently a sharp division of opinion in the society, and some members, including the sons of Priestley and Watt, resigned.

In 1793, Manchester Academy decided to employ John Dalton as a tutor, and he joined the society in 1794. With this powerful mind to aid it

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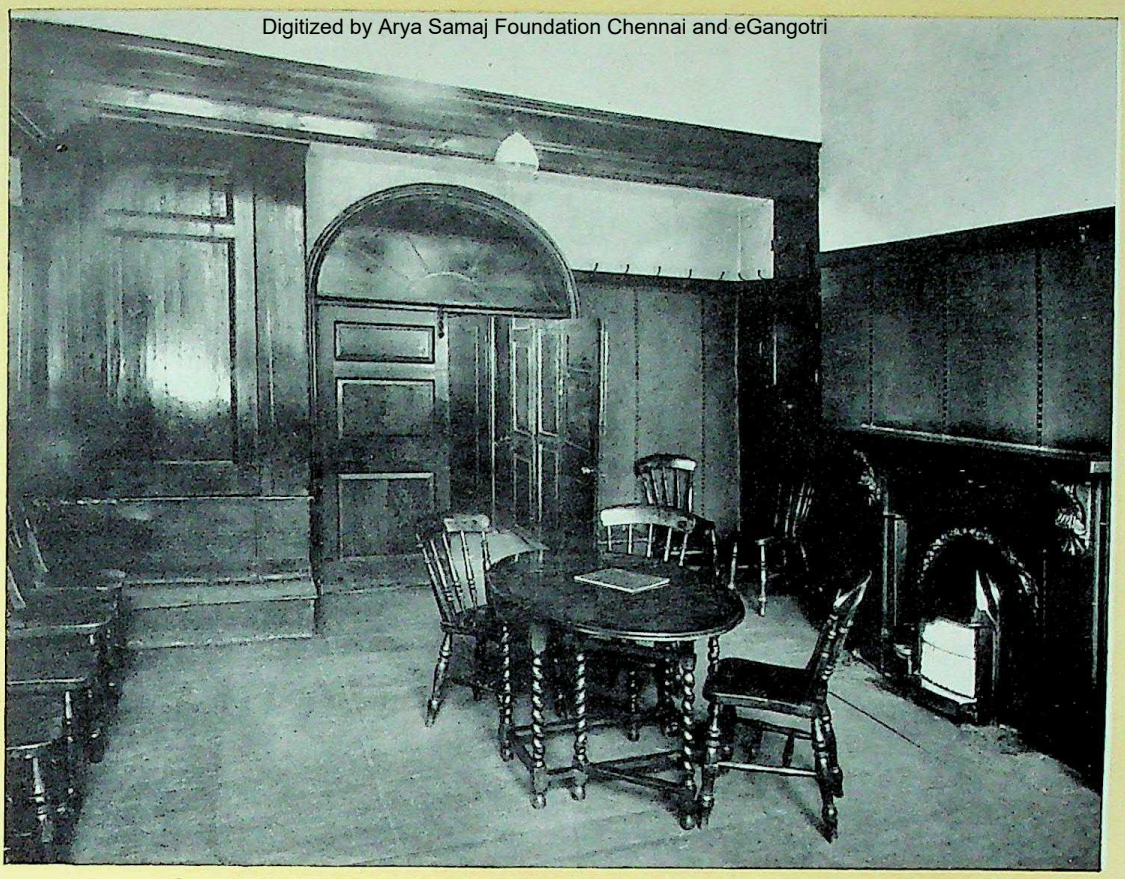

FIGURE 1 – *Cross Street Chapel Room, Manchester, in which the society's meetings were originally held.*

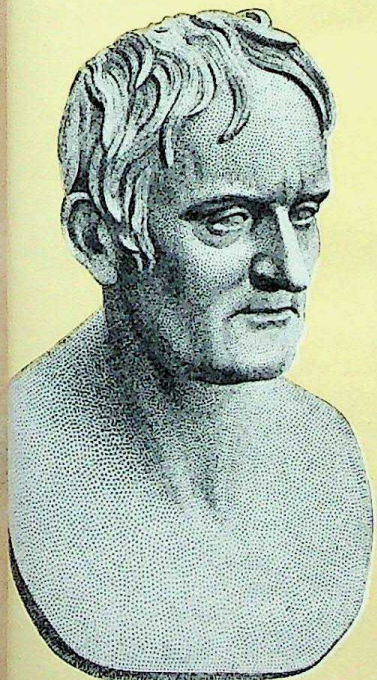

FIGURE 2 – *John Dalton.*
(From Memoirs of the Life and Scientific Researches of John Dalton, *by W. C. Henry*)

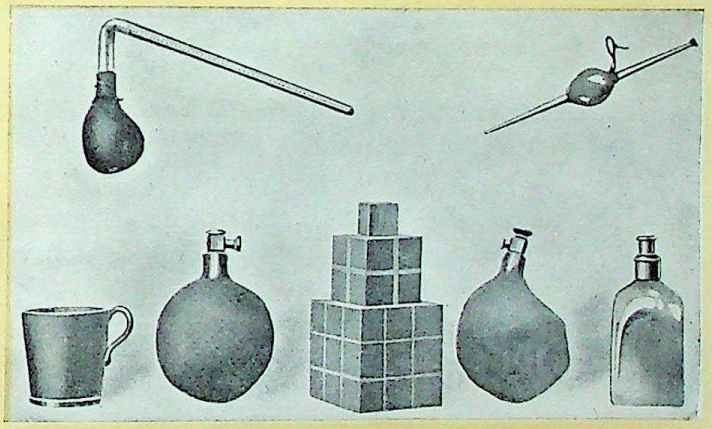

FIGURE 3 – *Some of Dalton's apparatus, destroyed in an air attack on 23rd December, 1940.* (*From* Makers of Chemistry, *by E. J. Holmyard*)

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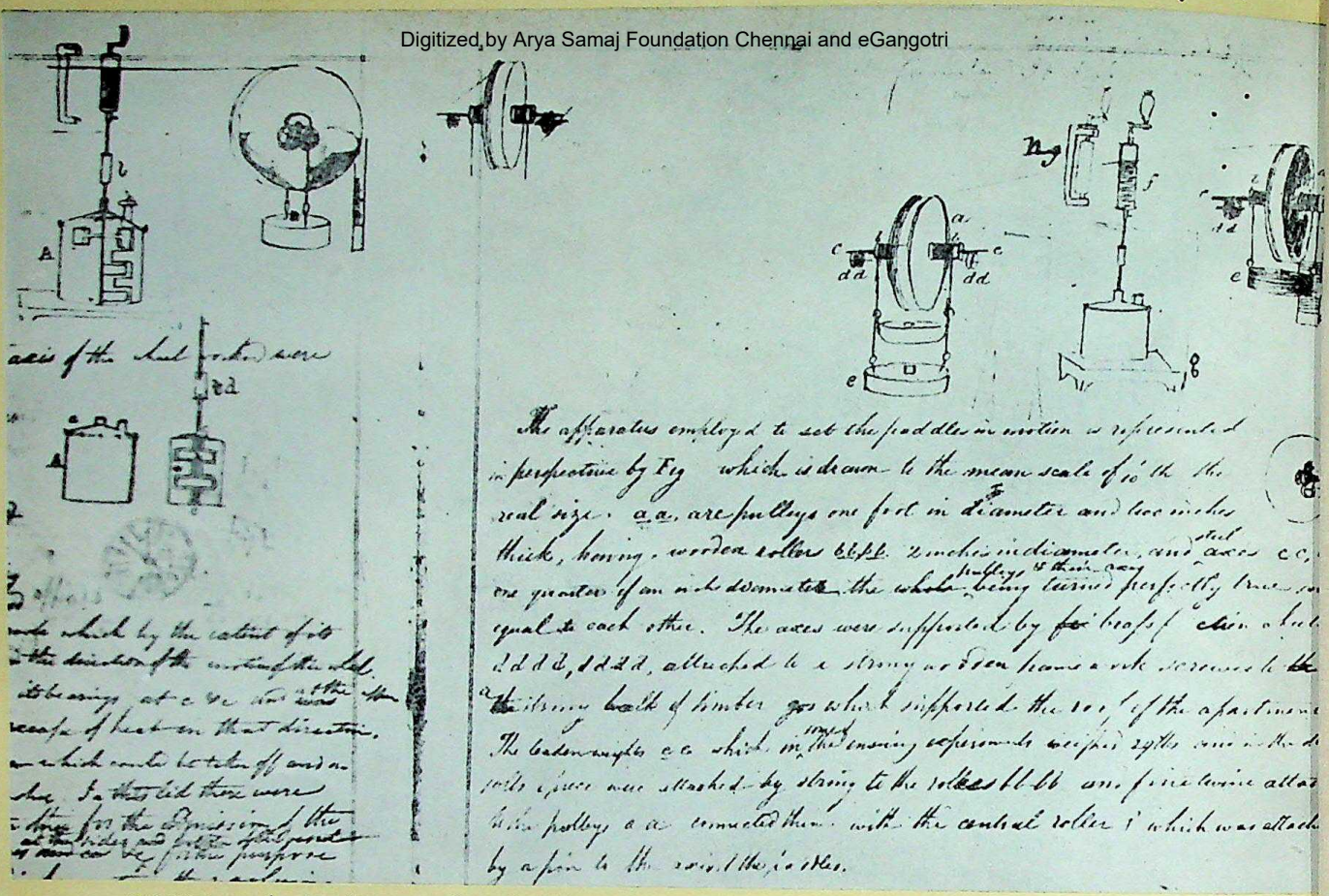

FIGURE 4 – *A copy of a page from Joule's notebook in which he sketched and described his plans for the final determination of the mechanical equivalent of heat.*

the society developed remarkably, and it has been calculated that during Dalton's fifty years of membership he read to it 116 papers, of which twenty-six are published. He became Secretary in 1800, Vice-President in 1808, and President from 1819 until his death in 1844.

Soon after joining, he read his first paper, which was the historic one on grades in colour-blindness, a paper that was based on his own defect of vision. Dalton's treatise on meteorology was another pioneer effort of his early days, and he continued to work at the subject until the end, his last paper being on the climate of Manchester. His most important work was the enunciation of the atomic theory, and a study of Dalton's efforts in this matter was published by Dr Andrew Meldrum in the society's Memoirs for 1910–11 (vols. liv and lv, New Series).

In 1799 a house at 36 George Street was bought for £600 by the society. Dalton was given a room in which to work and teach, and he lived for many years with the Rev. W. Johns in Faulkner Street not far away. As Manchester Academy was moved to York in 1803 and did not return to Manchester until 1840 (to move again in 1853, first to London, and then to settle at Manchester College, Oxford), the society's help to Dalton was no doubt very practical; it was certainly peculiarly appropriate, as the society owed its prestige almost entirely to his work.

Going back to the early days of the society, we find another name that was to become celebrated. The young Robert Owen attended for the first time in 1793, when Dr Guthrie read a paper on the nature and cultivation of Persian cotton. Owen was invited to join in the discussion, a sign that his work in connection with the improvement of fine cotton-spinning was already becoming known. During his residence in Manchester he read papers to the society on the improvement of the cotton trade (1793), the utility of learning (1793), the connection between universal happiness and practical mechanics (1795), and the origin of opinions with a view to

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the improvement of social virtues (1796). They at any rate show the trend of thought which was later to produce such interesting practical results.

The Rev. Thomas Barnes, the first secretary and minister of Cross Street Chapel, was evidently a man with a social conscience ahead of his time. To a paper read by him before the society is ascribed the idea of the 'Mechanics' Institute.' The Mechanics' Institute of Manchester was founded in 1824, and was the germ of what has now become the College of Technology.

Until the forties of the nineteenth century, topics discussed by the society ranged widely, though it seems that Dalton was little inclined to vague literary discourses. H. H. Watson worked on the effloresing properties of salts of sodium; W. Fairbairn (later Sir William) published elaborate figures concerning the strength of cast iron; and other papers dealt with the Rohan potato, the jargonelle pear, the coal of south Lancashire, the Babylonian or arrow-headed characters, and so on.

In 1842, J. P. Joule joined the society; he became its honorary secretary four years later. Times were changing rapidly in science. Specialization was developing quickly, and the Royal Society of London was becoming metamorphosed into the form it has now kept for nearly a hundred years, with election to its fellowship managed through specialist committees and very restricted as to numbers. Henceforth papers on literary and artistic topics became rare in the meetings of the society, and remained rare until an effort was begun by W. B. Wright, Honorary Secretary in the nineteen-thirties, to reintroduce these subjects.

The society soon began to suffer from the fact that papers which in earlier times might have been given to it were more and more sent to specialist societies of national status or to the Royal Society. Owens College, handsomely endowed by John Owens, was founded in 1851, and from the first some of its professors, notably W. C. Williamson, took an active interest in the society, but the institution had still to gather strength and prestige. It was increasingly felt that specialist memoirs were liable to be overlooked if they appeared in the memoirs and proceedings of such a general society as the 'Lit. and Phil.' The centenary volume of the Memoirs and Proceedings is, in places, almost querulous over this matter. It would seem that the officers and readers of papers had little realization of the field of work that Robert Owen, in his studies for social welfare, Thomas Barnes, with his educational projects, and Thomas Percival, with his concern about coal smoke, had opened up. The new prestige of the Royal Society of London was another overwhelming influence.

Henry Wilde, inventor of an improved dynamo and of better searchlights and other electrical equipment, enlarged the George Street House and gave the society about £10,000, from the interest on which a secretary's salary was paid and part of the cost of the memoirs was met. The house had by this time become one of Manchester's historic monuments, with a fine common-room containing furniture ascribed to Sheraton, portraits in oils of Newton, Davy, Dalton, Joule, Percival, and others, and a collection of Dalton's diagrams relating to the atomic theory, as well as a large collection of portraits of scientific men presented by Dr Francis Jones in memory of his father, who was Honorary Secretary 1896–1906 and President 1910–11. There were many pieces of Dalton's apparatus, his medals (including the Copley Medal of the Royal Society), and some thermometers and other objects used by Joule. But the greatest treasure of the society was its library of long runs of scientific periodicals and publications such as the Challenger Reports, the Palaeontographical Society's series, *Palaeontologia Indica*, and many more. Dalton's *Elements of English Grammar*, published by him in 1801, was among the society's intimate possessions, and it had many rare old works. In the period after the war of 1914–18 Mr R. H. Clayton, as Treasurer and President, gave much time and liberal gifts for the improvement of the house, and the Carnegie United Kingdom Trust made a considerable grant towards the binding of journals in the society's library.

The difficulty of the society was that it was living on its past, and its function was too largely that of custodian of what had become a historic house. In 1940 advice was given to the society, and unfortunately accepted, that it could keep its treasures in safe custody in its cellars. The air attack on Manchester on 23rd December, 1940, started a huge fire which spread from Piccadilly and destroyed 36 George Street so completely that only a few damaged items were ever recovered from the cellars. The society was kept alive throughout the war years 1939–45, and now appears to be entering upon a new phase of life, in which the University of Manchester, the citizens who are concerned for social betterment, and the great industries which increasingly need scientific contacts for their staffs, are playing a part.

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The colours of marine animals

T. A. STEPHENSON

The functional nature of biological coloration has been studied for many years, but the greater part of the observation and experiment has been done in connection with land animals. Professor Stephenson here suggests that new fields of inquiry might be opened by consideration of the coloration of marine animals and outlines our present knowledge, with particular reference to sea-anemones. He discusses also the possibility, not always recognized, of colour schemes which are not related to physiological or ecological functions.

For many years authors have been writing about the functions of colour and pattern in plants and animals; yet, considerable as the resulting literature is, it pales beside that of some other branches of biology. Thus, while the bibliography of H. B. Cott's recent book (1940), *Adaptive Coloration in Animals*, includes 685 references, that of J. Needham's *Chemical Embryology* (1931) includes about ten times that number. For the animal kingdom, this literature has culminated in the masterly book by Cott just mentioned. This enables us to see quite clearly what has already been achieved, and shows that the knowledge we so far possess is in some ways more solid than it had seemed to be. It may be accepted that schemes of colour and pattern which conceal, advertise, or disguise their possessors are of fundamental importance in the lives of animals. Cott's conclusion that 'adaptive coloration is one of the chief attributes of the higher animals, and has been, indeed, one of the main achievements of organic evolution' is probably by no means an exaggeration. It is therefore possible to regard Cott's book as a landmark, the end of an epoch. Without implying that there is not still plenty of scope for further development in the same direction, we may consider whether there are other directions in which a new start might now be made.

It is possible that new light might be gained by a closer study of the colours and patterns of water animals as distinct from land animals, because they offer a rather different field and one less fully known. That they have received less than their share of attention is evident from Cott's book, which reflects the literature and which, although it takes marine animals (especially fishes) into account where anything is known about them, is predominantly a book about land animals. This is well brought out, for instance, by the references to coelenterates, which contribute little to the conclusions of the book, whereas these animals actually provide one of the richest fields for colour studies in the animal kingdom. This is not a criticism of the book, but a comment on the state of our knowledge.

Various interesting questions arise in connection with water animals. Why are marine animals so often brilliantly coloured and fresh-water animals so often dull? Do all the principles which have been shown to affect the coloration of land animals really apply in the sea? Do they explain what we observe in the sea wholly or only partly? Are there further principles which apply in the sea and not on land? Many such questions may be asked.

A line of study which might prove very profitable is the inquiry as to how far colour and pattern are ever *irrelevant* to the life of an animal. This would lead on to a consideration of the real meaning of non-functional colour schemes. Here again it is possible that the sea may provide better examples than the land. Although authors have long recognized that there exist types of coloration to which no functional meaning can be assigned in the present state of knowledge, attention has hitherto been focused far more upon the types with which it has been possible to link some function.

Marine animals present both explicable, or partly explicable, types of coloration and types for which no explanation is yet possible. The illustrations to this article give examples of both. The sea-urchins in plate II and the dog-whelks in plate III show examples of coloration connected with sea temperature in the one case and food supply in the other; though in the first case we do not know how the temperature affects the colour, and in the second there is probably more variation than can be explained entirely in terms of food. The sea-urchins shown develop their bright colours throughout the southern

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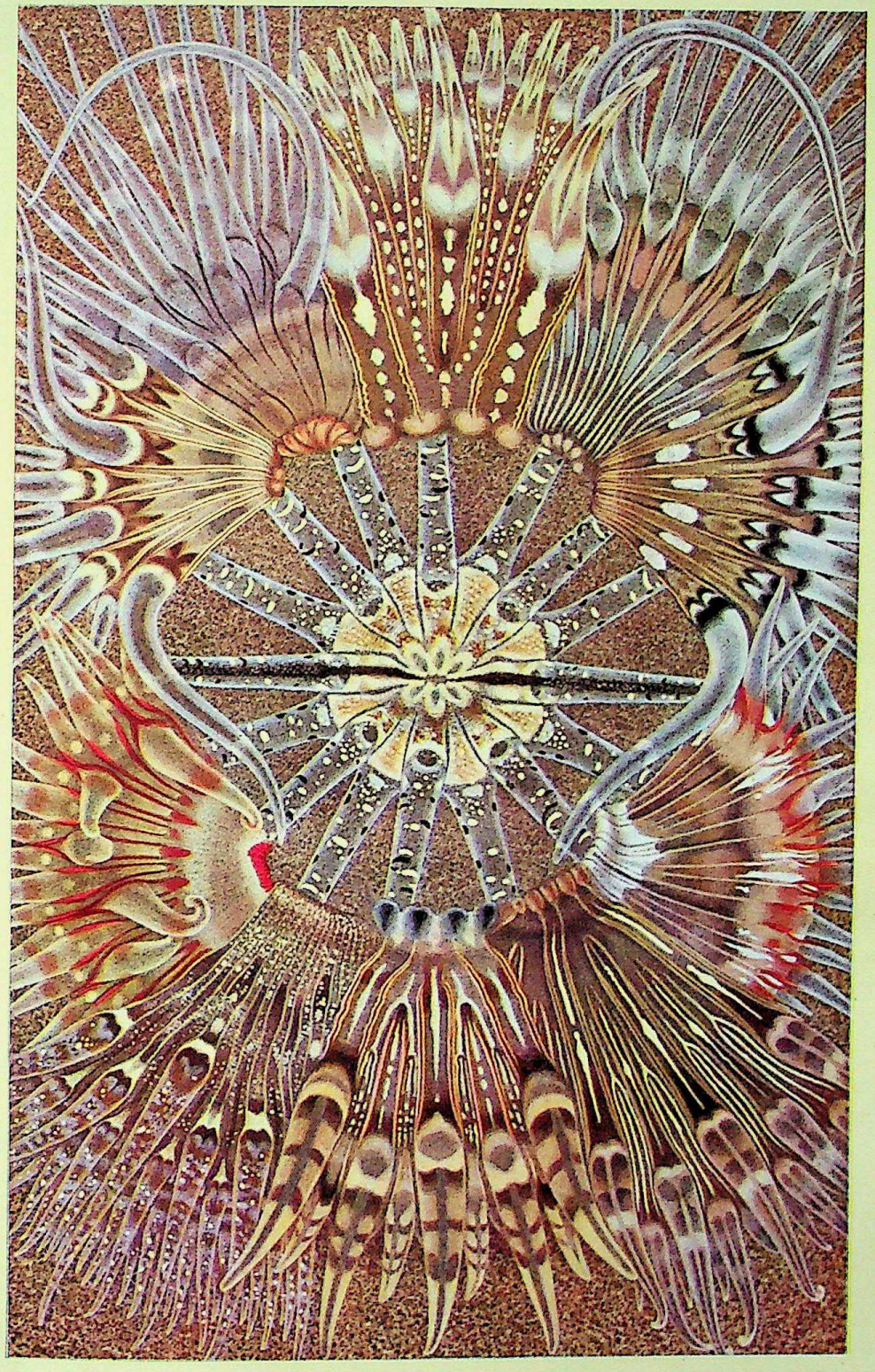

PLATE I – *The structure of the patterns developed on the disc and tentacles of eleven species of sea-anemones, represented on an enlarged scale. Except for the central figure, which illustrates the whole disc and the basal parts of the tentacles of a species of* Edwardsia *(with a dark line marking the directive axis), each figure represents a sector of the disc only, extending from the anemone's mouth outwards, with the tentacles belonging to it. The various sectors are arranged so as to facilitate comparison of the patterns with one another.*

(Reproduced from The British Sea Anemones, *by T. A. Stephenson, by kind permission of the Ray Society)*

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PLATE II – *A group of sea-urchins* (Parechinus angulosus) *in a rock pool in False Bay, South Africa. The purplish colour of the rock is due to an incrustation of calcareous algae. The small pentagonal objects in the lower part of the picture are specimens of a starfish* (Asterina exigua) *which also shows changes of colour, connected with water temperature, on different parts of the coast.* (*See page* 152.)

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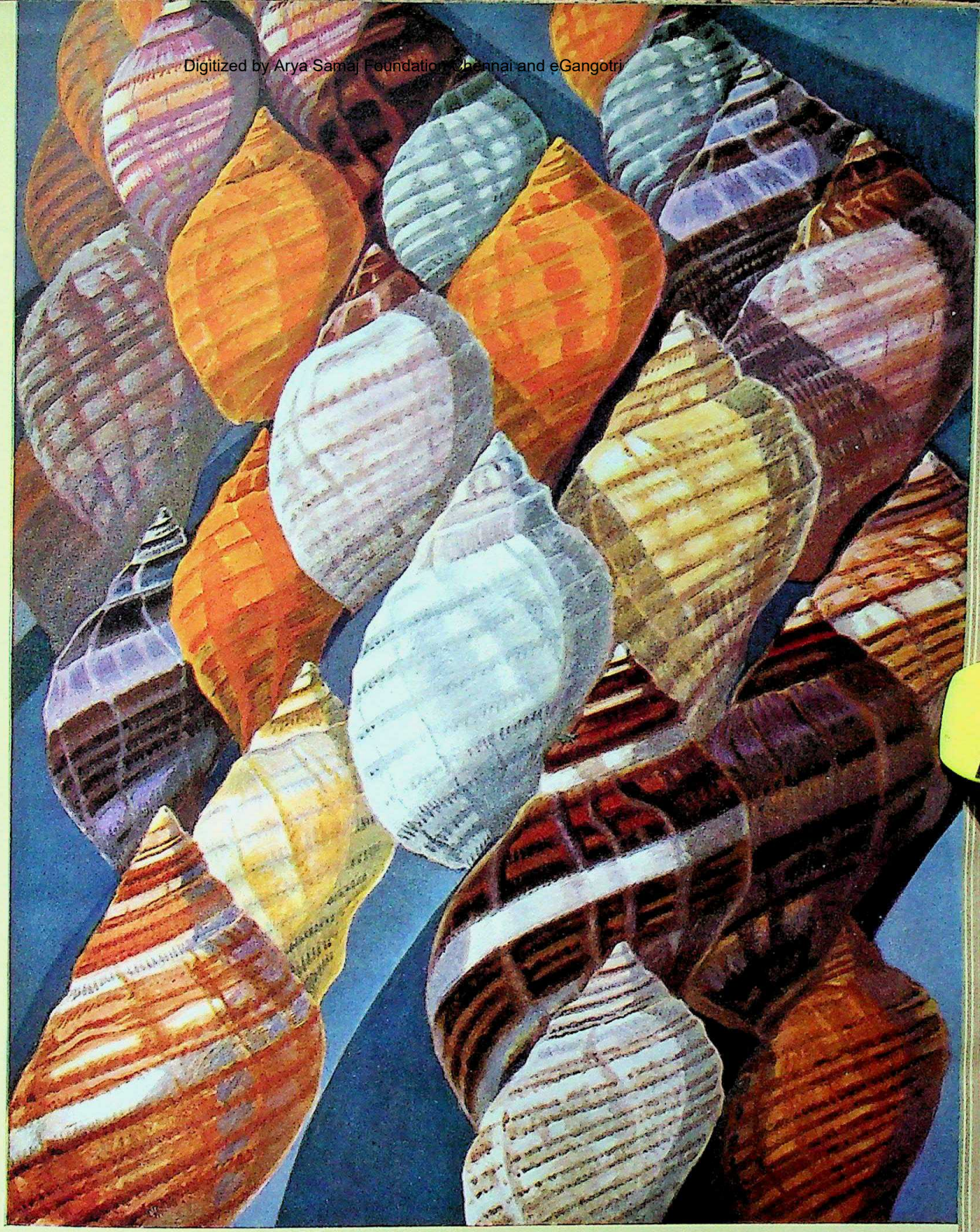

PLATE III – *A series of shells of the British dog-whelk* Nucella (Purpura) lapillus, *showing some of the variations in colour which occur in this species.* (*See pages* 153 *and* 158.)

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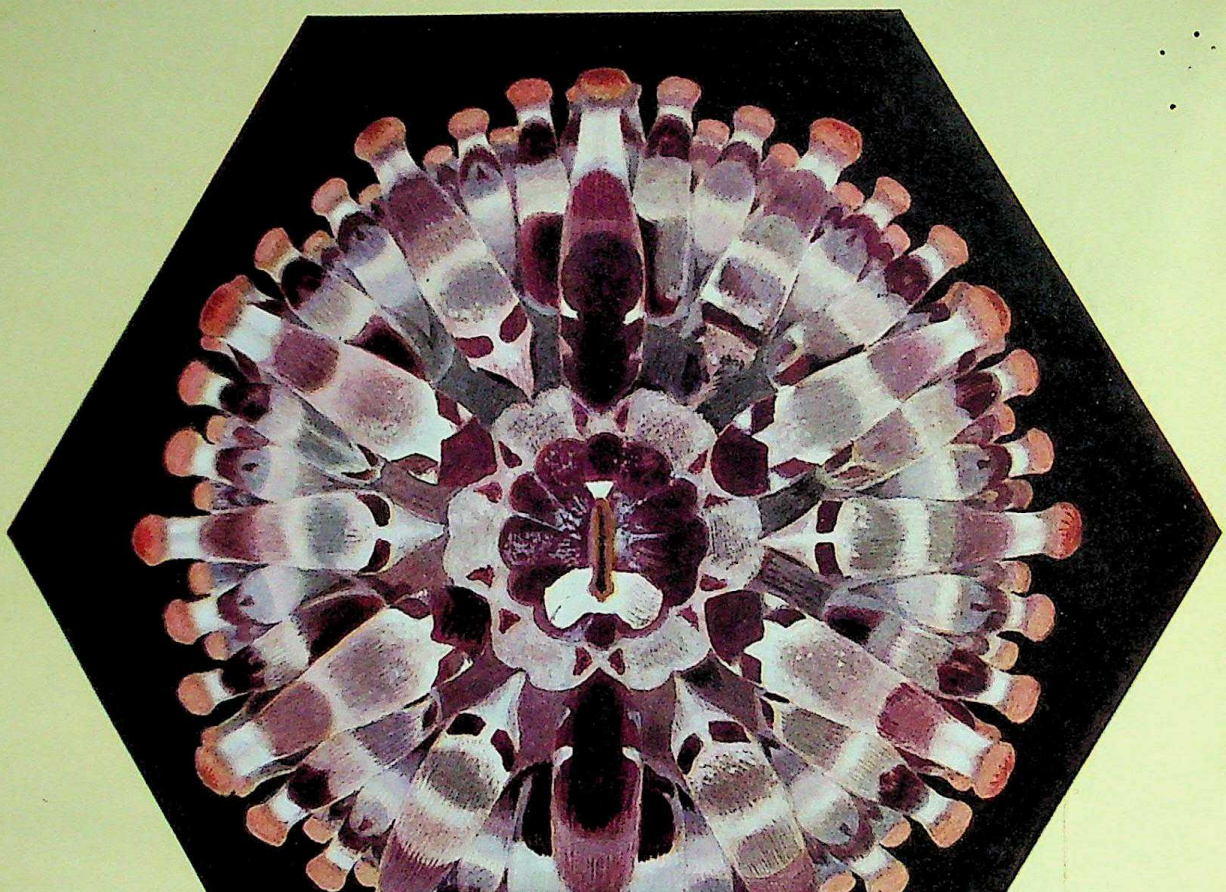

PLATE IV – *The disc and tentacles of a sea-anemone found in the interstices of branching coral on the Great Barrier Reef, Australia (about twice natural size). Some of the features of the pattern developed by this specimen are further illustrated in figure 2. The pattern is related with mathematical precision to the structural axes of the animal, and the coloration along the directive axis (vertical in the figure, and explained in the text) differs from that of the other radii in that there are opaque white marks at the opposite ends of the mouth, and much more dark colour on the two primary tentacles which lie along this axis than on the others. This change of pattern along one axis, taken together with an imperfection in the pattern in one sector (to the right of the upper directive tentacle, at* H *in figure* 2*), has a 'disruptive' effect on the general appearance of the animal as seen during life, distracting the eye to a certain extent from the very regular appearance presented by the rest of the pattern.*

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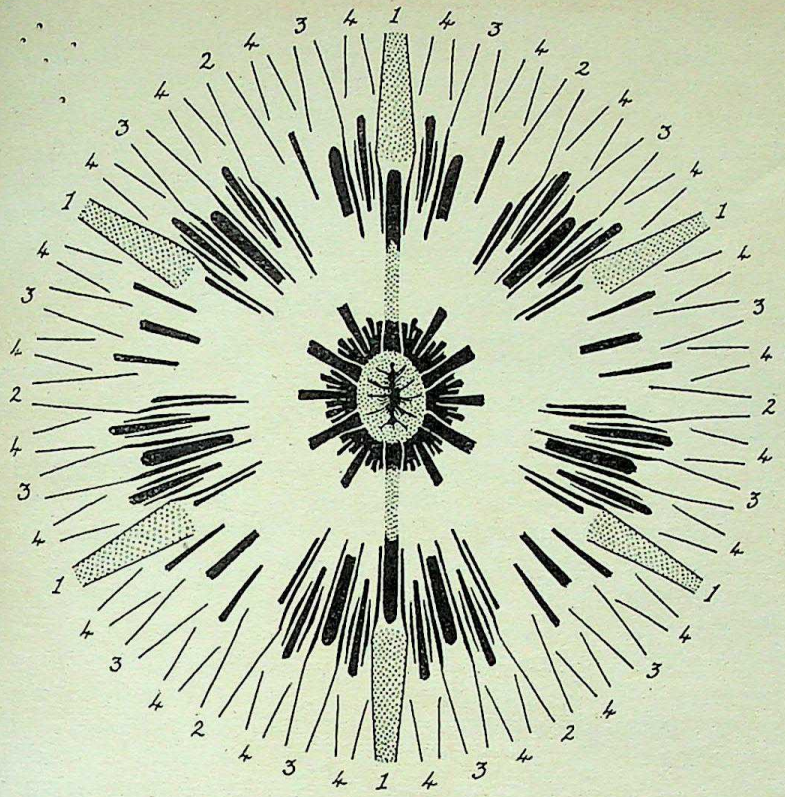

FIGURE 1 – *Diagram illustrating the bilateral arrangement of the pattern on the disc of a specimen of the sea-anemone* Calliactis parasitica. *The radial markings which, in the living animal, are carried out in opaque cream on a translucent ground, are here represented in black on a white ground. The six primary tentacles are stippled; the directive radii and mouth are also stippled, to indicate the directive axis. Only the four inner circlets of tentacles are included, and the circle to which each belongs is indicated by a number. It is to be noted that the six groups of pale markings are not centred about the six primary tentacles; on the contrary, while two of them (one larger than the other) are centred about the directive tentacles, the other four are centred about tentacles of the third series, and are symmetrically disposed with relation to the directive axis. The most conspicuous* individual *pale markings are not six but seven in number, and occur on six symmetrically disposed tertiary radii with the addition of the upper directive radius.*

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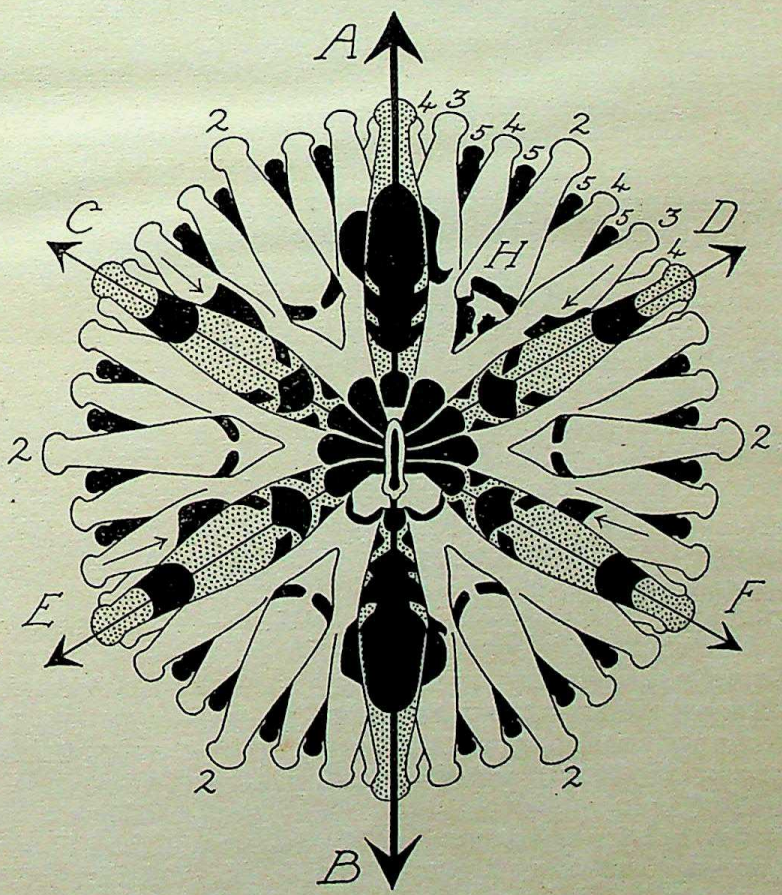

FIGURE 2 – *Diagram emphasizing some of the features of the pattern on the disc and tentacles of the sea-anemone illustrated in plate IV.* AB = *directive axis;* C, D, E, F = *primary non-directive axes. Primary tentacles and radii stippled.* 2 = *secondary tentacle;* 3–5 = *tentacles of outer circlets, numbered in one sector only.* H = *a tentacle at the base of which the pattern is not normally developed. The four small inwardly directed arrows indicate patches of dark colour which are symmetrically placed with relation to the directive axis but are not symmetrical about the primary radii. Similar patches flank the directive tentacles. The small tentacles of the outermost (fifth) circlet do not occur all the way round the periphery (if they did there would be forty-eight of them, whereas there are actually twenty-four), but only in the part of each sector centring about a secondary tentacle: there was a departure from this rule only in one sector, in which there were two additional tentacles (not shown). Further explanation will be found in the text and on plate IV.*

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(warm-temperate) part of their geographical range. On the northern part of the west coast of South Africa, where the water is colder, the pallid variety becomes dominant and the scarlet and violet ones scarce or absent. On the northern part of the east coast, where the water is subtropical, the bright colours again disappear and the specimens are all of dull reddish and greenish shades. In the case of the dog-whelks it has been shown by H. B. Moore that the pigments responsible for the pink and lilac, brown and black types of coloration are derived from mussels eaten by the whelks, and that these types are correlated in abundance with the proportion of mussels in the diet. These whelks also eat barnacles. The yellow coloration of other individuals was not shown to have any connection with diet but was suspected of having an indirect correlation with the degree of wave action to which the animals are exposed. Examples of the inexplicable type of coloration are given in the other two plates, and these are described in detail below. One which is not illustrated here, but which has been studied by Fox and Pantin, may also be mentioned. This is the sea-anemone *Metridium dianthus*, a large species in which the animal is sometimes entirely white, sometimes wholly orange, and sometimes brown and other colours. As a result of their study these authors consider the possibility that the colours of *Metridium* may be in a certain sense 'non-significant' and that 'the vivid colours of the anemones may signify freedom from certain environmental restraints, rather than any functional adaptation.' This is a courageous conclusion, because it is too often assumed that all coloration must have a direct physiological or ecological function. While this prejudges the issue in one direction, it is equally prejudicial to assume that there must be more in coloration than can be explained in functional terms. Possibly, however, a fuller investigation of the apparently non-functional, or at least at present inexplicable, types may, if pursued with an open mind, lead to a juster assessment of the true position.

The coloration of sea-anemones, already referred to, is a very fertile field for study because these animals are common, are easily kept alive for experimental purposes, and exhibit a complexity of pattern the significance of which is realized by very few people and which nobody understands more than very imperfectly. Some anemones are coloured simply enough—body and tentacles all the same colour, or body one colour and tentacles another, with no special markings. Others have a mosaic-like pattern of variously shaped and coloured markings which may be as elaborate as the design on a Persian carpet. Examples of such patterns are shown in plates I and IV. They have some very remarkable features. The anemone itself has a cylindrical body covered by a circular 'disc,' in the centre of which is the mouth; the peripheral part of the disc bears radiating tentacles. The disc also shows radiating lines which are all that is visible externally of the internal organs known as 'mesenteries.' These landmarks—a centre, radiating lines, and a circle—set the stage for the pattern. With strict relation to them, markings of various shapes are placed with mathematical accuracy. The pattern is by no means determined in its details solely by these visible landmarks, but is also related to invisible radii and concentric circles parallel with the visible ones. Each species of anemone has a particular pattern which is characteristic of it, but this pattern is merely a theme upon which many variations can be played. Just as a single pattern can be printed on material in different colours, so can the anemone pattern vary in colour. It is easy to see, also, that the pattern on a length of material could be varied in other ways. Some of its features could be heavily emphasized and others lightly indicated; some could be left out altogether; the shape of each element in the pattern could be varied; the whole thing could be speckled over with irregular stippling or modified by printing larger areas of different tints right across different parts of the pattern. All these devices are followed by individual anemones of the same species, using the same basic theme all the time. Sometimes an individual drops out the pattern altogether and is coloured in one or more uniform shades. Naturally these variations produce different effects, some conspicuous and startling, others inconspicuous and inclined to merge with their backgrounds. The situation is complicated by the fact that conspicuous individuals (e.g. blazing white and orange) and inconspicuous ones (e.g. an intricate mosaic pattern of browns) of one and the same species will occur under identical circumstances in the same pool; and these may be accompanied by pure white and bright pink forms, again belonging to the same species.

Has this coloration any value in the anemone's life? This question cannot be answered with any finality until far more field observations and experiments have been carried out than have yet

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been made. There are indications, however, which make functional explanations seem rather unsatisfying or which suggest that, even if the explanation is partly functional, it is partly to be sought elsewhere. The coexistence in the same pool of individuals exhibiting 'warning' and 'protective' types of coloration has just been mentioned, and it must be remembered that some at least of the animals which eat anemones possess such limited powers of vision that there is no question of their being able to see the patterns as we do. Again, some anemones simulate their background (e.g. they may look like gravel), as do many land animals. This effect is easily achieved by a quite irregular, non-mathematical pattern with no relation to the structural landmarks of the animal; why then, if the simulation of gravel is the object to be achieved, should so many of the patterns exhibit so marked and precise a mathematical complexity when it can be done without any such elaboration? Moreover, in the group of anemones taken as a whole, there are far too many of these patterns. It is probable that several hundred anemone species exhibit complex patterns and that no two of them are identical; and some of them are remarkable to a degree. Probably the great majority render their possessors inconspicuous, but why is this done in so many mathematically different ways?

It explains very little to point out that as an anemone grows these patterns result automatically from the periodic deposition of pigment at various points in the tissues. This orderly growth, taken alone, should produce results, in different individuals of a species, of the same order of uniformity as regards colour patterns as it does for the details of anatomical structure. This does not happen at all. While a genetical analysis would illuminate the problem from some points of view, it would probably reveal the mechanism itself more fully than the reasons for it. It is a current view that if any variant of a species exists in a reasonable proportion of individuals it must necessarily be beneficial, at least in a great majority of cases. This view (e.g. 'if a form occupies even a small percentage of a population, it must normally have reached that frequency because it is beneficial') is well stated, for instance, with the reasons which have led to it, by E. B. Ford in his recent book, *Butterflies* (1945). The reasons are seductive and convincing, and the argument of this article is by no means intended to be set in opposition to them. Yet one has a feeling that just as our knowledge of the interaction of variation and natural selection is now a very different thing from what it was in 1900, the next fifty years may reveal further influences, as yet unsuspected or only partly known, which may make possible a modification of current theory in the direction of showing that variations which are neutral as far as their survival value is concerned play a larger part than is now supposed.

One thing about these patterns, however, is abundantly clear, and that is that they are related to certain structural axes of the animal in a much more fundamental and apparently inexplicable way than is generally realized; it is by following up this side of the picture that the most interesting progress might be made. Most anemones, when looked at from above the tentacular crown (as in plate IV and figures 1 and 2), are obviously radially symmetrical, and the radii, while following various numbers, most often occur in multiples of six, so that there are six chief radii, along which lie the six largest (primary) tentacles. Alternating with these are six secondary radii and tentacles, twelve tertiary ones, and so on, every species having its characteristic arrangement. There is, however, in nearly all anemones, a further axis, known as the 'directive axis,' which crosses the whole tentacular crown (passing through the slit-shaped mouth and along two of the primary tentacles), dividing the animal into halves. What this directive axis is, nobody knows; but it has been shown to be of fundamental importance in development, growth, and regeneration; and every structure, inside the animal and outside, is related to it. The result is that the symmetry represents an intricate fusion of a radial pattern related to the tentacles and mesenteries, and a bilateral pattern related to the directive axis. The coloration of disc and tentacles, like everything else, obeys this principle; and while it is not possible in this brief article to enter upon a detailed description of the patterns illustrated in plates I and IV and in figures 1 and 2, a close study of those figures will confirm what has just been said. The example shown in figure 1 (*Calliactis*) is peculiarly noteworthy, for we have here an anemone which, in the arrangement of its tentacles and mesenteries, is as neatly and regularly six-rayed as any anemone known; yet the pattern of cream-coloured splashes on its disc has little relation to the six-rayed basis, and is not only itself partly seven-rayed but is related with great precision to the directive axis.

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The improvement of British grasslands and pasture

T. G. B. OSBORN

The proper maintenance of grassland depends ultimately on the skill and care with which the farmer manages his land, but the plant breeder is able to render very valuable assistance by producing new strains of grass suitable for specific localities and for various agricultural purposes. From the biological point of view the problem is an ecological one. This important fact was first clearly recognized and applied by Sir George Stapledon and his colleagues, to whom modern progress in grassland utilization is in large measure due.

Green fields and grassy hills are so characteristic a feature of the British landscape that many people are apt to forget that the grasslands are for the greater part made by man. They exist because man has learnt to maintain a collection of herbaceous plants which can survive and even flourish despite repeated grazing and cropping. Pasture is not a natural community of grasses and herbs in balance with the climatic factors and soil conditions: it is an assemblage of such plants together with the grazing animals which feed upon it.

The climax vegetation of Britain below 800–1,000 ft., and possibly even higher, is woodland. For centuries, and in the case of the Downs (the chalk uplands of southern England) from prehistoric times, the inhabitants of these islands have cut and destroyed trees to provide open areas for the growth of grass or crops.

How quickly and completely grassland may revert to woodland, even on long-cultivated arable land, is seen in the classic Broad Balk 'Wilderness' at Rothamsted. In 1882 Sir John Lawes ordered that a strip of land in full crop, running across the top of his experimental plots for wheat cultivation on the Broad Balk field, should be left unharvested to see what would happen. In four years the wheat had been entirely ousted by invading plants; today the area is a piece of oak woodland with the commonly associated shrubs and undergrowth.

There are many problems of grassland establishment, utilization, and improvement which await scientific help. The history of pasture improvement in Britain is a long one. Ryegrass was sown in the seventeenth century, and the introduction of Dutch clover, a form of the common British white clover (*Trifolium repens*), occurred only a little later. Sinclair's *Hortus Gramineus Woburnensis* (1824) records the experiments instituted by the then Duke of Bedford in 'the produce and nutritive qualities of different grasses and other plants used as food by domestic animals.' Even then certain species of grasses and clovers were recognized as suitable for use in permanent pasture, others on dry uplands, and others in alternate husbandry, a precursor of modern ley farming. The work of Robert H. Elliot at Clifton Park involved the use of seed mixtures of remarkable complexity in an attempt quickly to re-establish sown pastures that would be as valuable as first-class old permanent grassland. Some simplification of the seed mixtures, and in particular a recognition of the importance of wild white clover, was the contribution of Gilchrist as a result of his experiments at Cockle Park. The difficulty in these pioneering efforts was that the results were unreliable. The sown species disappeared and were replaced by the less valuable natural herbage of the district.

The modern progress in grassland utilization in Britain is due in large measure to Sir George Stapledon and his colleagues. He has always insisted that the problems involved are primarily ecological. Progress in plant genetics, which has led to the breeding of special types of grasses and clovers, has given the modern grassland farmer a far greater quantity of suitable plant material with which to build up his sward than had his predecessors even twenty years ago. In the end, however, it is only by an understanding of the ecology of the constituent species and of the sward which they form that the artificial community can be maintained.

The grasslands of Britain may be divided into three categories: the rough grazings, the permanent grasslands, and lands under temporary grass. The latter are known as leys. The rough grazings generally lie at high altitudes. Many are important grazing grounds for sheep or cattle, and

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FIGURE 1 – *Aberystwyth strains of wild white clover,* Trifolium repens, *S*100 (*left*) *and S*188 (*right*). *The more erect leafy habit of growth and later flowering of the strain S*188 *are evident.* (*Reproduced by courtesy of the Director of the National Institute of Agricultural Botany, Cambridge*)

FIGURE 2 – *Two strains of timothy grass,* Phleum pratense. *On the left is a commercial hay type of timothy grass, showing tall stems and relatively few leaves. On the right is an improved hay type of timothy grass, with considerably increased foliage, thus giving greater weight of nutritious fodder.* (*Reproduced by courtesy of the Director of the National Institute of Agricultural Botany, Cambridge*)

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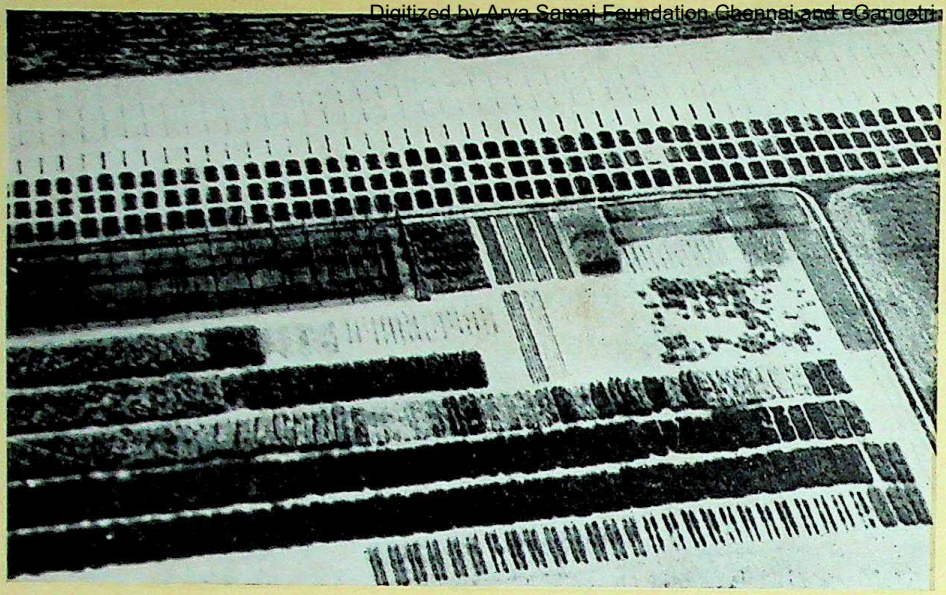

FIGURE 3 – *Aerial photograph of plots of grasses and clovers, National stitute of Agricultural Botany, Cambrid*
(Reproduced by courtesy of the Director of the Insti

FIGURE 4*a* – *Unimproved natural vegetation of the Welsh hills, showing growth of bracken fern* (Pteridium aquilinum), *gorse* (Ulex nana), *and coarse non-nutritious grasses. (Cahn Hill Improvement Scheme.)*

FIGURE 4*b* – *Neighbouring field o improved pasture after ploughing, treat ment with fertilizers, and sowing pastur grasses with wild white clover. (Cah Hill Improvement Scheme.)*

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their due utilization plays an important part in the national economy. Many of their problems are economic, as must always be the case with marginal lands. Their importance to the country may be realized when it is remembered that in England and Wales they have an area of about five million acres, roughly one-sixth of the total agricultural area of the two countries. In Scotland more than ten million acres are classified as 'mountain and heath land for grazing.' There is no doubt that considerable improvement of the grazing of many hill pastures is possible, with consequent improvement of their carrying capacity. The Cahn Hill Improvement Scheme, started in 1933 in association with the Welsh Plant Breeding Station, has done valuable pioneer work in this direction.

Permanent grass includes fields which are either grazed or mown for hay, or both. In 1939 it covered more than fifteen million acres of England and Wales, and though the area has been considerably reduced as a result of the policy of bringing more land under the plough, it still occupies nearly half the agricultural area of the two countries. Permanent grasslands contain mixed assemblages of different grasses, clovers, and other herbs, and their value varies enormously. They all have this ecological feature in common—they are in a state of unstable equilibrium. Man controls the incidence of the biological factors by his systems of management, an art far older than the recognition of the scientific principles upon which it is based.

Revolutionary changes in the composition of a sward can be obtained by the application of various combinations of manures. The action of nitrogen in stimulating the growth of grasses, with a reduction in the amount of clovers, is well known. But, as Blackman [1] has shown, the effect on the clover may be due to competition for light.

The bulk of the permanent grassland in Britain has been built up over a period of time by unconscious selection from the indigenous plants of those species that fit particular niches in its composition. Ability to grow and reproduce under conditions of defoliation and trampling is essential for the survival of the plants composing it. Man, who determines the very existence of the assemblage of plants, can control only such things as at what season of the year, how frequently, and for how long the plants shall be required to submit to grazing and how severely they shall be punished in the process. By unskilful management, for example overgrazing followed by undergrazing, the growth of weeds and thistles will be encouraged [6]. The finest old permanent grasslands of Britain, such as occur in Leicestershire and in the Weald of Kent, contain an assemblage of plants built up in the course of time by the selective effect of this biological factor. The desirability of using grass seeds obtained from old pastures was noted by Sinclair as long ago as 1824. It was not till nearly a hundred years later that Stapledon began to accumulate his collections of cocksfoot and Jenkin his collections of ryegrass, including many from old pastures, that were to play such an important part in the building up of the Aberystwyth strains.

The temporary pastures are the short- or long-term leys—fields sown to either a single grass or clover species or to a simple mixture, grown for a time, and then ploughed in preparatory to a cycle of arable crops. The best modern usage, which in some respects is a return to the methods of alternate husbandry, would give a long ley a life of four, six, or eight years before it is ploughed in again. The problem in laying down such a ley has been to select such an assemblage of grass and clover species as will produce, within a season or two, a sward that will stand up to grazing or hay-cutting, or both, as successfully as one that has been built up by careful management over a period of time. What species should be grown, whence should the seed be obtained, and in what proportions should it be mixed in order that, during the stages of germination and subsequent competition between the mature plants, the sward will persist as a close-growing ground cover capable of being grazed or mown [2], [7]?

The problems that are involved in producing the seeds of pasture plants are very different from those affecting seed for cereal crops such as wheat. Cereals are normally self-fertilized; the desired hybrid variety having been raised, its multiplication is a relatively simple matter, since there is little fear of contamination by pollen from other varieties. On the other hand, most of the perennial grasses, as well as the important red and white clovers, are normally cross-pollinated. Indeed, a high degree of self-sterility exists among them. It follows, therefore, that a considerable amount of variability occurs in any natural population as a result of gene-exchange. The individuals in such a population may differ among themselves in a variety of ways. Some of these differences depend on physiological characteristics such as earliness or lateness of vegetative growth, season of flowering, and so on. This

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minute variability is acted upon by the environment in a freely interbreeding population of any species. In this manner ecotypes may arise.

It was in 1922 that Turesson [8] first published an account of his observations and experiments on several species of common plants occurring wild in different habitats and in different parts of Sweden. As a result he was led to formulate his conception of the ecotype as 'an ecological unit to cover the product arising as a result of the genotypical response . . . to a particular habitat.' The conception of the ecotype has stimulated ecological and genetical work over a wide field and has led to important conclusions as to the nature of species [4], [9]. The practical importance of the ecotype conception for grassland work has also been great. Viewing the problems of sown grass in the light of it one is tempted to think that, ideally, the different kinds of grasses and clovers required in a particular district or country should be developed locally, since only in this way can the full selective effect of the local environmental factors be obtained.

Stapledon records that in 1918, when making a tour of the grasslands of England in connection with work for the Ministry of Agriculture, his attention was drawn to the extreme variation in form to be observed between plants of cocksfoot (orchard grass), *Dactylis glomerata* [10]. Returning to Aberystwyth, and using the facilities afforded by the Welsh Plant Breeding Station, which was founded in 1919 by Lord Milford, he and his colleagues began an extensive study of grasses and clovers of agronomic importance. Stapledon concentrated his attention on cocksfoot. More than three hundred individual plants were dug up from representative habitats in Britain. Seed was obtained from Europe, the United States, and New Zealand. In all, over eleven thousand individual plants were brought under critical study. Some, because their erect-growing leafy shoots mingled with the flowering stems, were highly desirable for hay crops; others, because of their spreading habit and free tillering, were more desirable for pasture.

Work on other species—notably ryegrass, *Lolium perenne*—was directed by Dr (now Professor) Jenkin. Controlled breeding experiments showed that self-pollinating races could be obtained, but that in most cases such inbreeding had undesirable results. The decision was therefore taken to build up strains of interbreeding plants. A strain is not a homogeneous self-pollinating race; it is a mixture of races, cross-pollinating and showing a combination of characteristics desirable for the purpose for which it is produced [5]. Thus S23 (all the Aberystwyth strains are known by numerals preceded by the letter S) is a densely growing, leafy, late-flowering type of ryegrass persistent in pastures on good soils. It was derived from plants obtained from very old grazed pastures in the Midlands, Kent, Lincolnshire, and even Holland. S24, on the other hand, is primarily based on two ryegrass plants found in the wild state but not on grazed pasture. With their progeny, plants from New Zealand have been incorporated. The result is an early-flowering, leafy hay strain. A strain is as much a product of the breeder's art as of his scientific knowledge.

Having built up a desirable strain, the production of sufficient seed for the market demands constant scientific supervision [3]. Isolation of the growing stocks from other fields containing different races of the same species is obviously essential. Pasture and hay strains of the three main species of agronomic grass—cocksfoot, ryegrass, and timothy—have been built up at Aberystwyth and at the Scottish Plant Breeding Station at Corstorphine. With these and the appropriate strains of red and white clovers [11] the production of grass fields suitable for particular purposes and at particular seasons of the year can be undertaken with a feeling of assurance impossible even ten years ago.

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The evolution of locust control

O. B. LEAN

Since prehistoric times plagues of locusts have been feared as the forerunners of famine and suffering. For centuries man's only defence has been the destruction of the pest at the points of its immediate onslaught—a task hopelessly beyond the strength of small and isolated communities. Today, knowledge of the breeding and migratory habits of locusts has made it possible to locate the source of potential new outbreaks, and chemical methods are being used to destroy the pests before they can begin their destructive activities.

The foundation of modern locust control was laid in 1921, when Uvarov first propounded, as a working hypothesis, his fundamental phase theory. Before that date intensive anti-locust campaigns had been waged in the more advanced countries liable to periodic attack, but it is only since 1921, and particularly since 1938, that the campaigns have been planned intelligently with the purpose of preventing locust invasions of rich agricultural lands rather than as a last-minute defence of the crops. This change of policy from defence to aggression became accentuated during the war years, when the vital importance of protecting foodstuffs stimulated anti-locust efforts in an unprecedented manner.

In an earlier article in ENDEAVOUR, Imms[1] described the bionomics of so-called locusts. The latter is no precise systematic term but is used to describe those short-horned grasshoppers which may develop both gregarious and migratory habits. There are about eight kinds of true locust, with several sub-species and geographical races invading over eighty countries in Europe, Asia, Africa, the Americas, and Australasia. Though varying greatly in their habits and ecology, the phase theory appears to apply to all.

The locust species are extremely plastic in their morphological characters and behaviour, and the extreme forms may be so different that they were once regarded as distinct species. These forms are named the phases. At one extreme the individuals of *phase solitaria* behave as relatively inactive, solitary grasshoppers, exhibiting little reaction to the presence of their fellows. At the other extreme the individuals of *phase gregaria*, the true locust, possess highly developed gregarious and migratory habits which lead the immature stages to march in massed hopper bands and the adults to migrate long distances in dense swarms.

[1] 'Locust Invasions and their Control,' ENDEAVOUR (1943), II, 56.

The phase of a locust community depends upon population density. Thus a considerable number of *solitaria* hoppers developing in a restricted environment may become true locusts. Conversely, a few hoppers of true locusts developing in an unconfined space may revert to grasshoppers.

This is the barest outline of the phase theory, but it is of essential importance because the high policy of locust control depends upon its implications, just as the strategy of regional campaigns depends upon the seasonal cycle of the locust and the tactics of the separate battles upon the daily regimen of the hoppers or adults.

PREVENTIVE POLICY

Though entomologists of several countries have attempted to prove that locust outbreaks occur at regular intervals—usually in 11–13-year cycles—the data do not substantiate such a mathematical rhythm.

The sequence of events which initiate a locust outbreak are less obscure than the details of the ecological relationships which actually cause the transition of the phases. The solitary phases of several locust species are widely distributed, but it is only in certain limited localities, called outbreak areas, that favourable conditions may cause a concentration of population leading to gregariousness and the production of the swarming phase.

The solitary phase of the African Migratory Locust, *Locusta migratoria migratorioides* (R. and F.), is distributed throughout Africa, all Europe, and Asia south of latitude 60°. Swarms invade nearly all tropical Africa. In 1929 I witnessed swarms pouring into Nigeria, and such was the state of our knowledge eighteen years ago that this invasion came unannounced and its origin was not discovered until the swarm movements of the whole outbreak had been analysed. We now know that the original transition of *phase solitaria* into *phase gregaria* took place in 1928 within an area of seven

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thousand square miles among the swamps of the river Niger in the French Sudan. From this single focus swarms spread, generation by generation, during the subsequent nine years, until they covered ten million square miles of Africa. In British and French West Africa, Equatorial Africa, the Sudan, Eritrea, British East Africa, the Belgian Congo, and the Rhodesias costly campaigns were improvised to destroy each generation of hoppers, but in spite of all efforts the plague lasted until 1937 and crop losses were considerable.

The basic policy for the control of the African Migratory Locust became clear with the discovery of the Middle Niger outbreak area, even though it may not be the only potential danger spot. By controlling any undue multiplication of *solitaria* populations the development of *phase gregaria* and migratory swarms could be prevented.

The war interrupted the establishment of an international organisation as recommended at the Fifth International Locust Conference held in Brussels in 1938 to study the outbreak area, to keep it under continuous surveillance, and to eliminate any incipient swarming. The French, however, acting alone, founded a preventive service which has kept the zone under observation since 1939.

The control of the Red Locust, *Nomadacris septemfasciata* (Serv.), has progressed one stage farther. During the period 1930–8 entomologists of many nationalities dispersed into the interior of Africa and of western Asia and they returned with many discoveries. One of the most important was the demarcation of outbreak areas of the Red Locust on the Shores of Lake Rukwa in Tanganyika and the Mweru marshes on the borders of the Belgian Congo and Northern Rhodesia. An Anglo-Belgian control service was set up in 1941. The headquarters are in a British colony and the Director is a Belgian entomologist. As the Red Locust invades nearly the whole of Africa south of the Equator and some countries farther north, about eighteen territories benefit from this localized preventive policy.

The permanent prevention of the Desert Locust, *Schistocerca gregaria* (Forsk.), is a more complex problem that has yet to be similarly tackled. This is the most widely spread of all the locusts, as it ranges from Senegal and Morocco in West Africa to central India, and from Turkey and southern republics of the U.S.S.R., through the Arabian Peninsula, to Tanganyika Territory. Some outbreak areas are known, others are suspected, and it is clear that the plagues may develop from several widely separated areas in a manner somewhat different from the original conception of phase transition. Although preliminary aggregation may occur within definable limits, swarm formation may, with this species at least, be a more gradual process involving the migration of *solitaria* or intermediate forms from one seasonal breeding area to another, normally between zones of winter and summer rainfall. Areas such as the Mekran coast and both coasts of the southern Red Sea, where two climatic systems adjoin, are most dangerous, but the problem is greatly complicated by the irregular rainfall over much of the desert country inhabited by this species.

The establishment of an international preventive service was recommended at the Brussels Conference, but again the war intervened and at the same time a new outbreak of this locust, which began in 1940 and still continues, distracted thought from prevention to the more immediate problem of positive action against invading swarms. During the past seven years the Desert Locust has invaded over thirty territories, and the very high costs of the anti-locust campaigns—a total not computed but probably at least £15 million—has again focused attention on the need for international action and a policy based upon stopping swarm formation at the origin.

Unfortunately the picture is not clear-cut. Recent studies have clarified our ideas on the Desert Locust but much remains to be investigated. When an international body is formed its first duties should be scientific exploration to identify the danger areas and to elucidate all the ecological factors which may lead to the development of *phase gregaria*.

Turning to the New World, we find a similar problem. The South American locust, *Schistocerca cancellata* (Serv.), is best known in Argentina (which suffers more than any other country in the world from locust plagues), Uruguay, and Brazil; but it also attacks Bolivia, Paraguay, and Chile. Outbreaks in the north, in Peru, Ecuador, and Colombia may be linked with the southern activity of this species or may be independent.

Information on the South American locust is still fragmentary, largely because swarm movements have been studied only territorially. Yet again the necessity for international co-operation is recognized, and at a conference held in Montevideo in September 1946 representatives of nine states recommended the creation of a permanent Pan-American preventive organization.

A somewhat different but allied question is the

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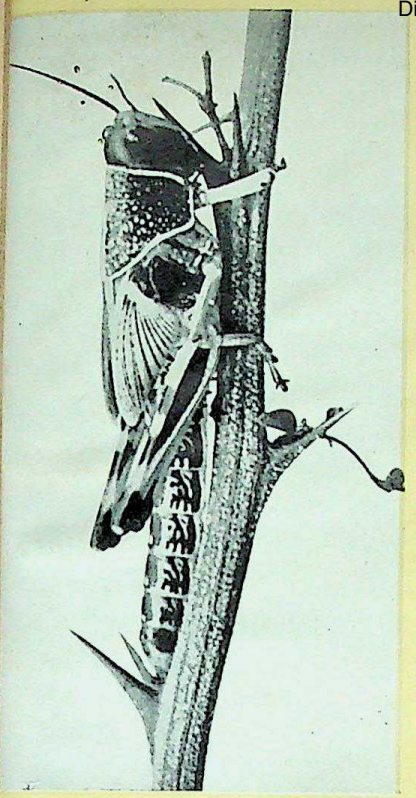

FIGURE 1 (*above*) – *Hopper of the Desert Locust*, Schistocerca gregaria. ($\times 1\frac{1}{2}$)
(Reproduced by permission of the Anti-Locust Research Centre, British Museum.)

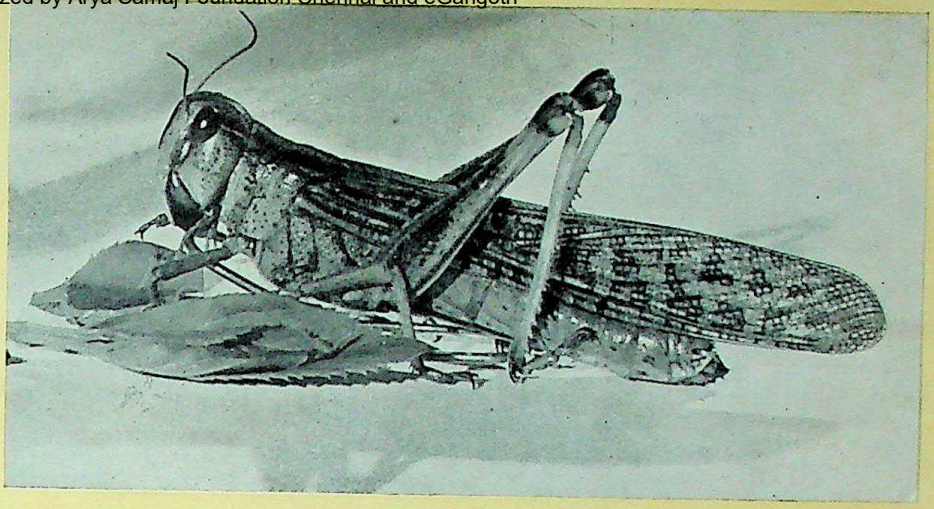

FIGURE 2 (*top right*) – *The African Migratory Locust*, Locusta migratoria migratorioides. ($\times 1\frac{1}{2}$)

FIGURE 3 (*right*) – *Mountain country of south Iran, typical of the country in which locust control work has to be carried out.*

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FIGURE 4 – *A pool of young hoppers, Eritrea.*

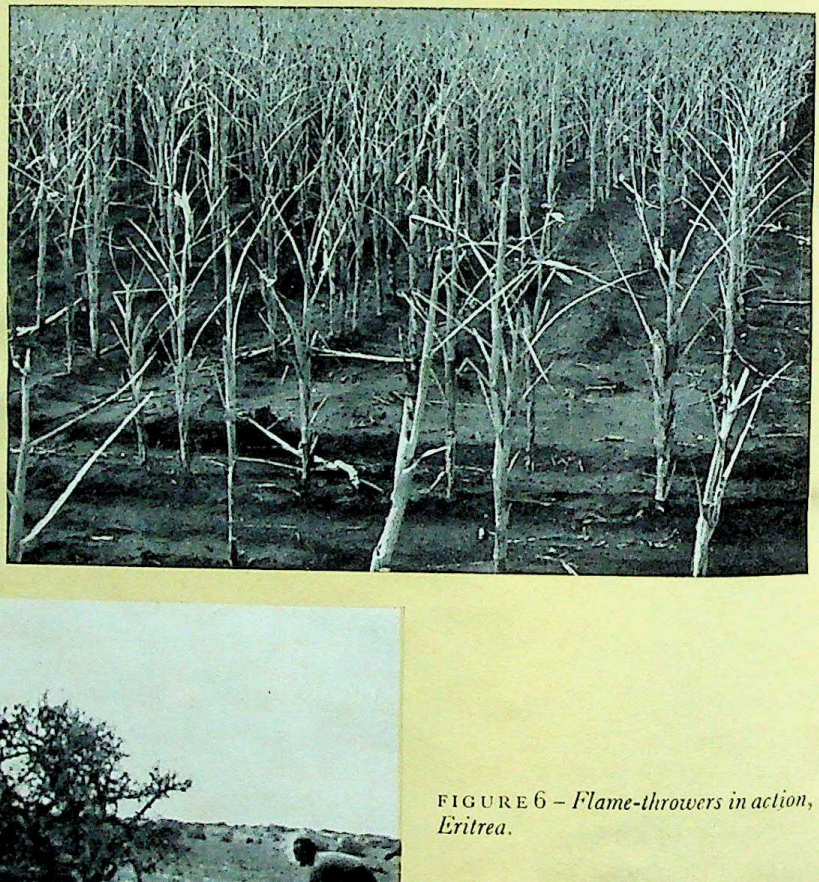

FIGURE 5 – *Maize stripped by hoppers, Argentine.*

FIGURE 6 – *Flame-throwers in action, Eritrea.*

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control of the Moroccan Locust, *Dociostaurus moroccânus* (Thnbg.), a Mediterranean species that extends from Spain and Morocco through southern Europe and Anatolia to Transcaucasia, Iran, and Afghanistan. This species is not migratory to the extent of the other locusts already discussed. Yet the factors responsible for swarm formation throughout its area of distribution are probably similar, and a practical preventive policy can be evolved only through centralized research.

SEASONAL STRATEGY

Each year during an outbreak swarm migrations and breeding follow a similar pattern. When locust swarms migrate from one country to the next and from continent to continent they are carried by the climatic tide. Locust species vary in their habitats and in their response to climate and eco-climate, but none can live or breed in extreme wet or dry conditions or in extreme temperatures, and the migrations help the species to avoid adverse environments.

The Anglo-Egyptian Sudan and the highlands of Eritrea have a tropical climate with a single rainfall maximum during the summer; the Desert Locust breeds throughout this climatic zone approximately from June to October. With the onset of the dry season swarms of the next generation are carried north-east to the Red Sea coast and more especially into Arabia, where the rains fall in winter. The Desert Locust also breeds during monsoon rainfall in north-west India, whence the young swarms fly westwards to the regions of winter rainfall around the Persian Gulf. Some may breed in south Iran, some across the Gulf in Arabia, and some may travel as far as Iraq—a flight of 1,200 miles.

The Arabian swarms bred during the winter and spring migrate generally north and west to invade the Euphrates valley, Syria, Palestine, and the Nile delta. The Iranian swarms of the same generation fly north into central Iran and sometimes as far as Russia. In all these regions breeding takes place during the late spring and the swarms of the next generation return to summer rainfall areas, the Iranian swarms to India and the Egyptian-Syrian-Iraqi swarms back towards the Sudan.

Arabia and south Iran are key dispersal areas during seasonal outbreaks, and though they are not agricultural districts it becomes worth while to attack the hoppers there in order to minimize any subsequent invasion of richer lands.

During the war British specialists, basing their strategy upon newly acquired knowledge of this cycle, accepted the major responsibility for these arduous and novel campaigns. Before the first reconnaissance of the interior of Arabia in 1942 such operations would have seemed impracticable, but by 1944 a complex organization had been built up, with motorized baiting parties penetrating practically the entire breeding area. In Arabia the British Middle East Anti-Locust Unit was assisted by Egyptian and Indian parties and by workers from the Sudan and Palestine; in Iran the British unit worked alongside Iranian, Russian, and Indian missions. Such international co-operation in the field was something entirely new.

Knowledge of the South American locust lags behind that of other species. Nevertheless we know that Uruguay receives its swarms from or through Argentina and that during spring the voracious immature southern swarms cross the western frontier to invade an agricultural belt. The best defence of Uruguay may lie hundreds of miles away, but until the origin of the swarms is certain they should be destroyed immediately they cross the frontier. The defence of the 270-mile frontier will prove difficult indeed, and the mobile swarms can possibly be best attacked from aircraft.

There is a popular but erroneous impression, fostered by publicity, that aircraft are the latest answer to the locust. Aeroplanes have been employed for many years, but mostly for speeding up operations that can be pursued from the ground. The real use for aeroplanes would seem to be against flying swarms, against which there is no other reply.

Air offensives are bound to be costly, and their future is likely to depend upon developing an extremely toxic contact insecticide—something comparable to 'Gammexane,' killing at a few grams per acre in bait. A fair-size locust swarm may measure 20 miles by 2 miles, covering 25,600 acres. At a dosage of half a gallon (5 lb.) per acre, of liquid insecticide, about 60 tons would be expended. A fleet of aircraft, requiring many people for maintenance, would be needed.

To destroy a few swarms by such means is not enough, but air spraying may become economic when it can prevent a widespread invasion of a country, thus saving the aggregate cost of damage to crops and of hopper campaigns, and if considerable reduction of dosage can be gained by improved technique, as seems possible from recent British research. The protection of Uruguay is a possible application, but even better would be the defence of some defile through which a seasonal migration is directed and where aircraft can

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strike at the swarms as they pass. While research on these lines proceeds, spraying from the air remains no more than a future possibility.

It is a mistake to conceive any anti-locust campaign as a set-piece. Early preparations demand a plan, but this must be flexible, and all units must be mobile. Battle headquarters, watching the trend of the locust invasion through daily radio reports from its detachments, will frequently require last-minute adjustments in the disposition of its forces to meet a changing situation. In 1945–6, for example, breeding in Arabia occurred exceptionally far north, and much of the area was out of reach of the detachments placed to meet a normal invasion.

No account of modern locust control would be complete without acknowledgment of the pioneer work in this direction of the Anti-Locust Research Centre of London. This British institution, recognized since 1930 as an international co-ordinating, advisory, and forecasting centre, has been the inspiration behind all recent developments and has provided the data upon which many operational plans have been built. The Centre forecast the present outbreak of the Desert Locust, and for the first time in history threatened countries were warned to prepare their defences. In the territorial anti-locust headquarters, whether at Baghdad, Nairobi, Teheran, Jedda, Damascus, or Asmara, one can examine current situation maps plotting swarm movements, oviposition, and hopper infestations, and all these are pieced together by the Anti-Locust Research Centre to build up the entire picture. Each country consolidates its local reports and telegraphs a fortnightly summary to London and to its neighbours, following up with detailed swarm lists. All records are scrutinized, tabulated, and entered on large-scale maps. The Centre circulates in return a monthly situation summary and forecast of probable developments. No rigid system can serve all needs, and reports come in from all manner of sources. These reports may be too delayed to be incorporated in current summaries, but they help the Centre in its fundamental study of migrations, and these studies will shape future locust policy and strategy. During the past sixteen years the Anti-Locust Research Centre has dealt with about 8,000 swarm lists, corresponding to perhaps 100,000 individual swarm records.

DAILY TACTICS

In early history the farmer relied upon charms for protection, and even as late as 1942 Koranic prayers were hung from poles among the Iranian crops. Hoppers have probably been beaten and burnt since earliest times, and even today such crude methods—rarely effective and always extravagant in man-power—are all too common. Then perhaps came trenching, with encircled hopper bands being driven into pits or trenches by armies of men, and though this technique involves much labour it has been widely used during the present outbreak of Desert Locust, particularly in India.

The introduction of metal barriers as a refinement of simple trenching marked a definite advance, and the method became extremely popular. It is still employed, for instance, in Syria and South America—Argentina alone possesses 20,000 miles of barrier. When an advancing band reaches the barrier the hoppers, turning to right or left, eventually fall into carefully constructed pits or corrals from which they cannot escape. The method is at best cumbersome and lacks mobility.

Flame-throwers—the modern equivalent of simple burning—were first used on a campaign scale in Palestine in 1918. They are so spectacular that their popularity, in spite of their inefficiency and high working costs, dies slowly, and during the past few years they have been employed in Eritrea, Tripolitania, and South America, with Argentina again in the lead with about 50,000 hand machines.

Chemical control began when hoppers were sprayed or dusted with a great variety of crude contact insecticides such as kerosene, crude oil, and caustic soda, and when vegetation upon which hoppers were feeding was treated with arsenicals. Modern chemical control dates from the introduction of poison bait, and the technique remains the basis of all modern campaigns.

Poison-baiting succeeds because locusts, particularly in the hopper stages, are more attracted towards certain substances than to their normal food plants. A contact poison must hit each insect, but locusts seek out poison bait and their own destruction. Bait consists of an attractive edible base or carrier and a stomach insecticide. A great variety of bases has been used. The earliest was chopped green vegetation, then came dung, and though bran is now the popular choice many other materials such as sawdust, chaff, oilseed residues, bagasse, ground millet stalks or maize cobs, and coffee parchment are suitable. The choice of carrier should depend upon local availability, with waste products preferred to animal foodstuffs. Whatever the material, its effectiveness

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depends largely upon the amount of water it will absorb and the slowness with which it dries out, as moisture is the principal cause of attraction.

The question of the poisonous ingredient is more important. Various arsenicals, particularly sodium arsenate, have been the most popular, though in some areas, including the United States, where there was a risk of poisoning domestic animals, sodium silicofluoride was favoured. Up to 1944 the commonest bait formula was 100 lb. dry bran, 1·5–2 lb. sodium arsenate, and 10 gallons water.

The introduction of benzene hexachloride as a bait poison in 1944 marks another milestone in the evolution of locust control. The principles of baiting remain unaltered, but two properties of the new poison have unlocked new doors. As it is non-toxic, in normal dosages, to higher animals, the new bait can be applied with complete confidence. This has permitted the introduction of locust control into the more backward countries where one fatal accident with sodium arsenite would have roused antagonism. It has accomplished a revolutionary change of attitude in the cattle-raising countries of South America, which are now turning to poison-baiting in place of more antiquated methods. Secondly, benzene hexachloride kills so quickly that the baiter is encouraged by seeing results within a few minutes.

The toxic component of benzene hexachloride is the γ-isomer, Gammexane. A standard bait contains 0·5 per cent. benzene hexachloride or about 0·065 per cent. Gammexane. From skilled hands 5 lb. of bait can, under good conditions, destroy an acre of hoppers. This means that less than 2 grams of the insecticide itself are applied per acre to kill perhaps five million insects. Only the experienced baiter, however, will kill an acre of hoppers with 5 lb. of bait. Bait itself is not expensive, but when it is shipped and then transported perhaps five hundred miles across the desert costs mount rapidly and strict economy becomes necessary.

The daily regimen of hopper behaviour, like the seasonal behaviour of swarms, is a cyclical series of responses to climate—eco-climates rather than regional climates. At low and high temperatures hoppers are immobile. At intermediate temperatures only slight fluctuations determine whether they feed without marching, feed while marching, or march without feeding. The line of march is not haphazard but orientated at least by wind direction, light, radiation, and topographical features. The locust-baiter can only gradually learn to expend his ammunition advantageously.

No single control method can, however, meet the diverse demands of locust control, and field techniques must vary and be as flexible as the entire anti-locust organization. Within recent years campaigning against the Desert Locust alone has been carried out under a bewildering variety of conditions. In Iran, 9,000 ft. up in the central plateau among a peasant farming community; in Syria, in the rich irrigated gardens around Damascus; in Transjordan, among the barren foothills of the mountains of Moab, a thousand feet below sea-level; in the Sudan, within the irrigated cotton-fields of the Gash delta; in the highlands of Abyssinia; in the empty deserts of Arabia; in Kenya, in the European highlands and the sparsely populated Northern Frontier Province; along the torrid coastlands of the Red Sea; down the wadis of the Hadramaut; beside the fertile Nile valley. Where water is scarce a dry bait can be used with success, and under similar conditions dusting with a contact poison may cease to be uneconomical.

Whatever the technique employed, simplicity of equipment and mobility favour effective kills. This is why poison-baiting has won its place as the leading method of control. Spraying or dusting machines, flame-throwers, or any other mechanical device give endless maintenance troubles.

ORGANIZATION

The spirit of international co-operation was fostered in various international conferences, but, although these are unavoidable and indeed necessary, real progress has resulted more from friendly and not too ritual exchange between the experts. Locust killing is skilled work and should be the responsibility of entomologists.

Locust infestations cannot be compared with attacks by less mobile insect pests, and locust control is accepted more and more as a government responsibility for the benefit of the community. This is in line with the need to develop broad research projects and to attack the locust wherever it can be reached, however far from cultivation. To pass responsibility from the farmer to the government is one stage, but units even larger than the individual country are required to oppose the locust successfully.

When the government takes over, operations can be planned scientifically, and the most successful present-day campaigns are run by self-contained locust control units. From his headquarters the entomologist in charge directs the operations to meet the ever-changing situation.

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Nitrogen fixation by blue-green algae

G. E. FOGG

The ability of certain bacterial species to fix atmospheric nitrogen has been known since the end of the nineteenth century and was discussed by Professor Quastel in the previous issue of ENDEAVOUR. Only recently, however, has it been proved that some species of blue-green algae are also able to fix nitrogen. Although this process is of little agricultural value in the soils of temperate countries it appears to be of great practical importance in certain tropical soils, such as the ricefields of India, and in maintaining the productivity of fresh water.

There can be little doubt that the capacity to utilize the free nitrogen of the atmosphere in the synthesis of cell material, a capacity possessed by a small minority of living organisms, plays a very considerable part in maintaining the fertility of the earth [1]. Whereas the importance of *Azotobacter* and of leguminous plants in this respect is recognized, a third group of organisms able to fix nitrogen, the blue-green algae, has received less attention. However, our knowledge of nitrogen fixation by the organisms forming this group, although still meagre, is beginning to increase sufficiently for an idea of their possible importance to be obtained.

The blue-green algae, or *Myxophyceae*, are primitive plants having certain resemblances to the bacteria, for example in undergoing no sexual reproduction and in the absence of a nucleus of the type found in higher animals and plants. In the order *Chroococcales* the individuals are unicellular and may occur singly or aggregated into colonies, for example in species of *Gloeocapsa*. Members of the more evolved orders, *Nostocales* and *Stigonematales*, are filamentous, for example *Petalonema*, *Anabaena*, and *Gloeotrichia*.

That some of these algae are able to fix nitrogen was first indicated by the work of Frank [2] published in 1889, four years before the first isolation of a nitrogen-fixing bacterium by Winogradsky. Frank's cultures were, however, impure, and the first pure cultures of algae which became available were found unable to grow in the absence of combined nitrogen. As a result it was generally assumed that algae, including blue-green algae, are unable to fix nitrogen, and that where they develop in the apparent absence of combined nitrogen it is because of association with nitrogen-fixing bacteria. This opinion prevailed until comparatively recently, plausibility being lent to it by the isolation of nitrogen-fixing bacteria from algal material [3]. The main difficulty in proving nitrogen fixation by blue-green algae attends the preliminary step of obtaining cultures free from other organisms. Pure cultures are necessary because even if contaminating organisms are known to be unable to fix nitrogen alone, the possibility cannot be precluded that they are able to do so in association with the algae. The gelatinous sheath with which most members of this group are invested provides a natural medium for the development of bacteria and renders their removal by ordinary culture methods exceptionally difficult.

The first well-substantiated claim for nitrogen fixation by blue-green algae was put forward in 1928 by Drewes, and was based on work with pure cultures obtained by a laborious method of subculture [4]. Since then new methods for obtaining pure cultures have been evolved, the most convenient appearing to be that using ultra-violet light, a suitable irradiation killing the bacteria but not the algae [5, 6]. Recent workers have paid particular attention to checking the purity of their cultures [7, 8], and there can now be little doubt that really pure cultures have been obtained. Conclusive proof of fixation by a given species requires not only the use of pure cultures but a reliable method of demonstrating an increase in combined nitrogen. In the majority of studies on algae the Kjeldahl method for the estimation of nitrogen has been employed. Its use in work of this sort is open to criticism [1], but in cultures in a medium initially free from combined nitrogen, such as have most commonly been used, the objections that have been advanced do not apply. Recently, nitrogen fixation by *Nostoc muscorum* has been demonstrated by the use of the heavy isotope of nitrogen as a tracer element [9]; this provides confirmation of the validity of the more generally used method.

There is now satisfactory evidence of the nitrogen-fixing powers of the following species of blue-green algae: *Nostoc punctiforme* [4, 6, 10], *N. muscorum*

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[9, 11], *N. paludosum* [6], *Anabaena variabilis* [4, 5, 6, 7], *A. gelatinosa* [7], *A. naviculoides* [7], *A. humicola* [6], *A. cylindrica* [6, 8], *A. ambigua* [12], *A. fertilissima* [12], *Cylindrospermum licheniforme* [6], *C. maius* [6], *C. gorakhporense* [12], and *Aulosira fertilissima* [12]. All these species belong to the same family, the *Nostocaceae*. Only further work can decide whether nitrogen fixation is confined to this one family, but meanwhile it is interesting to speculate on the possibility of other blue-green algae possessing the property. The known nitrogen-fixing algae may be exclusively *Nostocaceae* simply because members of this family are somewhat easier to culture than the others. The majority of blue-green algae have still to be investigated from this point of view. There is no lack of indications that species other than *Nostocaceae* may be able to fix nitrogen, and often they are found growing vigorously in environments very poor in combined nitrogen. Claims that species of *Oscillatoriaceae* and of *Chroococcales* possess the property have been put forward [13, 14], but in these cases there is no adequate evidence of the purity of the cultures used. Reports of blue-green algae found not to fix nitrogen are scanty, possibly because there is little incentive to publish such results.

Nitrogen fixation occurs only under certain well-defined conditions. As yet, fixation has never been found to take place in 'resting' material: active growth is essential. A further limitation is that assimilation of free nitrogen does not occur in the presence of readily available combined nitrogen. Thus ammonium salts or nitrates have an inhibiting effect, and fixation does not start until these compounds have been exhausted from the medium in which the algae are growing [8]. Although in pure culture growth on nitrate or ammonium nitrogen is as good as or better than that on free nitrogen, growth of nitrogen-fixing organisms in mixed culture tends to be suppressed by these compounds, since they are then exposed to the competition of organisms which do not fix nitrogen. Traces of molybdenum are necessary for the fixation of nitrogen by blue-green algae [6]. A slightly alkaline medium is the most favourable for the growth of nitrogen-fixing algae, and it has been found that fixation does not take place below approximately *p*H 5·7 [11].

Although it has so far been found impossible to extract the enzymes from the cells, there exists a good deal of information, obtained largely by physico-chemical methods, about the characteristics of the enzyme system responsible for nitrogen fixation in leguminous plants and in *Azotobacter* [1, 15]. The characteristics of the enzyme system in *Nostoc muscorum* have been investigated [16] and appear to be very similar to those found for other organisms. The half-maximum rate of fixation occurs at a partial pressure of nitrogen of 0·02 atmosphere. While this value is only provisional, it is evidently of the same order as that for *Azotobacter* (0·02 atmosphere) and for *Trifolium pratense* (0·05 atmosphere). Like those of *Azotobacter* and the symbiotic system, the enzyme system of *Nostoc* is specifically inhibited by hydrogen and by carbon monoxide. The biochemical mechanism by which fixation of free nitrogen is accomplished is still largely unknown, and so far studies on blue-green algae have contributed little towards the solution of the problems involved.

It is evident that the nitrogen-fixing system in blue-green algae is physiologically similar to that in other organisms. However, differences in general physiology render the natural role of these algae as nitrogen-fixing agents somewhat different from the parts played by *Azotobacter* or leguminous plants. An important respect in which blue-green algae differ from the nitrogen-fixing bacteria is that the former are photosynthetic whereas the latter are heterotrophic, dependent on already elaborated carbon compounds. Nitrogen-fixing blue-green algae are the most completely autotrophic organisms known, being able to synthesize their most complex biochemical requirements from carbon dioxide, water, free nitrogen, and mineral salts. Consequently these algae are able to flourish in situations where nitrogen-fixing bacteria cannot grow because of lack of carbohydrates, for example on bare rock faces and in open water. On the other hand, environments into which light cannot penetrate, such as all but the most superficial layers of soil, although suitable for bacteria, would appear unsuitable for algae. This is not, however, necessarily so, since some blue-green algae at least are able to grow and to fix nitrogen in the dark, provided that a suitable carbohydrate is available [10, 11, 17].

In combining the nitrogen-fixing and photosynthetic modes of nutrition, blue-green algae resemble the legume-nodule-bacteria system. However, in the latter the seats of photosynthesis and nitrogen fixation are spatially separated, carbon assimilation occurring in the green aerial parts of the plant and nitrogen assimilation in the root nodules. Even so, the two processes are closely interrelated [1]. In blue-green algae, in which nitrogen and carbon assimilation proceed side by side in the same cell, this association may

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be yet more close. There may be, for instance, common intermediate compounds. In rate of growth blue-green algae are intermediate between bacteria and leguminous plants. Under favourable conditions of culture *Anabaena cylindrica*, for example, is able to double its bulk in a little under twenty-four hours [18].

The nitrogen fixed by blue-green algae eventually passes into general circulation and is assimilated by organisms unable to fix it for themselves. There are two possible ways in which the nitrogen compounds formed may be released. They may be excreted or lost by diffusion into the surrounding medium during the life of the algae, or they may be released by death and subsequent decomposition or digestion. The filtrate from healthy cultures of blue-green algae may contain a considerable proportion—up to 50 per cent.—of the nitrogen fixed in a soluble organic form [7, 8, 17]. Such excretion is relatively greatest in young cultures [19] and thus cannot be the result of autolysis of senescent cells. Since organisms unable to fix nitrogen are able to grow to a certain extent in healthy cultures of nitrogen-fixing algae, it seems that they are able to assimilate the excreted nitrogen compounds to at least a limited degree. Like other nitrogen-fixing organisms, blue-green algae have a high nitrogen content of from 7 to 8 per cent. on a dry-weight basis [18], and a correspondingly low carbon/nitrogen ratio of 10 : 1 [7]. The bacterial decomposition of organic matter with a carbon/nitrogen ratio of this low order will lead to the immediate production of ammonia [7], a form of combined nitrogen readily available for the growth of higher plants.

It remains to consider the importance of blue-green algae as nitrogen-fixing agents in the various habitats in which they are found. In any particular instance it is necessary to know, not only to what extent nitrogen-fixing species are present, but whether the physiological conditions are such as to allow the process to take place. The presence of available combined nitrogen and the absence of molybdenum would seem to be of chief importance in preventing the assimilation of free nitrogen. It has been shown [20] that traces of molybdenum are widely distributed in nature, and it seems safe to assume that sufficient for the fixation process is present in most habitats.

Blue-green algae are common in neutral or alkaline soils but are rarely present under acid conditions [21]. They are more abundant in the surface layers of soil [21], although the demonstration that some species at least are capable of heterotrophic growth suggests that they are not necessarily confined to the most superficial layers exposed to the light. Besides forms which have definitely been shown to be nitrogen-fixing, there are many other species which probably also possess the property. The concentration of nitrate in the soils in which they occur is generally sufficient to inhibit assimilation of free nitrogen, but it is probable that conditions of shortage of nitrogen compounds may arise locally—particularly on the surface—and permit the process to take place. While blue-green algae are of general occurrence in soils of agricultural value in temperate regions in which conditions suitable for nitrogen fixation may sometimes arise, it may be doubted whether their nitrogen-fixing powers are of much importance in contributing to fertility, since it has never been demonstrated that they occur in sufficient quantity.

In certain tropical soils, on the other hand, blue-green algae appear to be of extreme importance in maintaining fertility. In India, rice may be grown on the same land for many years without the addition of manure to the soil. During the season of growth of the rice the soil is waterlogged, and growth of blue-green algae, including several species that have been shown to fix nitrogen, is very luxuriant [7, 12]. There is good evidence that such algae are the main agents responsible for maintaining the level of fertility of the ricefields, and the part played by bacteria is probably unimportant [7].

Blue-green algae are frequently abundant in fresh water, the phenomenon of 'water bloom' being due to a copious growth of planktonic forms. They are especially characteristic of neutral or alkaline waters with relatively high contents of dissolved organic matter [22]. Some of the species concerned are *Anabaenas* and almost certainly fix nitrogen as has been claimed [23, 24], but rigid proof of this is still wanting. Other types of planktonic blue-green algae, for example *Gloeotrichia natans*, are still unexamined for nitrogen-fixing properties. At times when these organisms are most abundant the nitrate content of lake water is very low [22] and is probably not high enough to interfere with fixation. It has been reported [23, 25] that, in bodies of fresh water where they are abundant, these algae are the chief agents responsible for increases in the amount of combined nitrogen in the water. This is probably generally true, since the combined nitrogen of a 'bloom' of blue-green algae may be many times the amount of combined

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nitrogen apparently available for its growth, and fixation of free nitrogen is therefore indicated [19]. *Myxophyceae* may thus contribute to a considerable extent to the productivity of fresh water in which they occur.

Blue-green algae are commonly the first plants to colonize bared areas of rock and soil. The best-known example of this is seen in the recolonization of Krakatoa after the volcanic explosion of 1883 which denuded the island of all visible plant life. Blue-green algae were the first plants to appear on the pumice and volcanic ash, on which they formed a dark-green gelatinous layer a few years after the eruption [26]. Members of the group are equally important pioneers under less impressive circumstances. Thus, to give only two of many possible examples, a community of blue-green algae forms the initial stage in plant succession on certain eroded soils [27], and *Myxophyceae* play a conspicuous part in the colonization and stabilization of salt marshes. In part, their success as colonizers is no doubt due to a marked ability to withstand adverse conditions such as desiccation, extreme temperatures, and high salt concentrations, but a capacity for nitrogen fixation cannot be discounted as a possible factor determining their presence on unpromising substrates. Again, there is no conclusive proof that among the blue-green algae which are conspicuous as colonizers some are able to assimilate free nitrogen, though many species occurring in lists of algae in pioneer plant communities belong to the *Nostocaceae* [26, 27]. There is, however, a certain amount of evidence that blue-green algae colonizing rocks under desert conditions are able to fix nitrogen and are therefore responsible for an accumulation of nitrate [14].

Besides free-living forms there are many blue-green algae that occur in more or less intimate association with other plants, for example with certain liverworts, with the water fern *Azolla*, with cycads, and with the flowering plant *Gunnera*. Many claims have been made that *Nostoc punctiforme*, the alga found in *Gunnera* and some cycads, is able to fix nitrogen, and in at least one case [10] the evidence appears sound. The species of *Anabaena* which are also found in such associations have not definitely been proved to possess the property. While in many cases these blue-green algae can be grown in artificial culture, this is sometimes difficult [6]. *Nostoc punctiforme*, isolated from cycads, has been found to be scarcely capable of autotrophic nutrition, and needs to be supplied with carbohydrate for growth and nitrogen fixation [10]. The host plant is generally able to exist if uninfected with the alga, and it is not clear how much benefit is derived from the nitrogen fixed. In some cases, for example that of *Azolla*, growth in a medium free from combined nitrogen is made possible by the presence of the algal partner [6]. There is thus a certain amount of evidence that these associations are symbioses, though they are neither so highly developed nor so successful as those between *Leguminosae* and their nodule bacteria. The plants concerned are not widely distributed, and if nitrogen fixation does occur it is not likely to be of very great importance either ecologically or economically. Blue-green algae form symbiotic associations with fungi as well as with green plants, the algal partner in many lichens often being a member of the *Myxophyceae*. Nitrogen fixation may well be important in enabling some of these composite organisms to live on bare rock and in other similarly inhospitable situations.

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Book reviews

HEAT-TREATMENT OF METALS

Controlled Atmospheres for the Heat-Treatment of Metals, *by Ivor Jenkins, with a foreword by C. J. Smithells. Pp. x + 532, with 268 figures, including many plates. Chapman and Hall Limited, London.* 1946. 50*s. net.*

The heat-treatment of metals in controlled atmospheres is a process of great and increasing practical importance. If carried out in the ordinary atmosphere, the various heat-treatments to which metals and alloys are subjected during manufacture generally result in surface oxidation. The loss of metal due to this and to the cleaning processes involved may be enormous. It is estimated, for instance, that the value of iron lost in this way amounted to about one million pounds sterling per annum in Britain alone prior to 1939, and in non-ferrous metals the losses are probably similarly expensive. To reduce these losses and ensure a proper finish, suitable atmospheres must be employed, but this is not such a simple matter as merely protecting the metal from oxidation. With steels, carburization and decarburization of the surface layers must be controlled, and nitride-hardening may be desirable; with copper, embrittlement due to deoxidation must be avoided. The essence of the problem is generally to ensure a state of true equilibrium between the atmosphere and the metal over the range of temperature employed.

Despite the extremely technical nature of the subject, this is a remarkably readable book. The problems belong essentially to physical chemistry rather than to metallurgy, and the book begins with a simple and very clear treatment of chemical equilibria and some discussion of gas-metal systems. The generation of commercially feasible controlled atmospheres (derived from ammonia, hydrocarbons, or charcoal) is then described. An excellent section on analysis is followed by a very full account of industrial applications of controlled atmospheres to various steels and alloys. The fundamental scientific problems involved are stressed throughout the book, and the result is a work of really great interest to the student and academic worker as well as to practitioners in this important field. The publishers are to be congratulated on their production of an attractive volume of industrial high quality.

J. M. ROBERTSON

CRYSTALS AND MINERALS

Kristalle und Gesteine, ein Lehrbuch der Kristallkunde und allgemeinen Mineralogie, *by P. Eskola. Pp. viii + 397, with 461 figures. Springer-Verlag, Vienna.* 1946.

This work, which first appeared in Finnish and is now available in a revised German translation, is divided into five sections of approximately equal length—crystal geometry, crystal physics, crystal chemistry, petrology, and systematic mineralogy.

Within this compass it is clear that the treatment of the subjects indicated cannot be deep; nevertheless the material of the general survey is presented in an attractive form. The author finds room to include tables of the 230 space-groups, short notices on Fourier analysis, radioactivity, geochemistry, and petrofabric analysis, but here the presentation is all too brief.

In the section on metamorphism of rocks the treatment follows closely, though in an abbreviated form, that presented by the author in *Die Entstehung der Gesteine* (1939).

The last section gives a brief survey of crystal types, with special attention to substances illustrating the variety of crystal structures met with among minerals.

The volume is well printed and illustrated and provides an outline of the broad field of study among crystals and rocks.

C. E. TILLEY

SILK

Bibliography of the Technical Literature on Silk, *by F. O. Howitt. Pp. xxiv + 248. Hutchinson's Scientific and Technical Publications, London.* 1946. 21*s. net.*

Students, research workers, and technologists whose work and studies touch upon the production, properties, and processing of silk at any stage will find in Dr Howitt's critical and exhaustive review of the published literature on silk an indispensable aid and will be grateful to the Council of the British Cotton Industry Research Association for sponsoring its publication.

Such is the antiquity and wide geographical distribution of silk that it has acquired to itself almost a technical word-group of its own, and readers will find the Glossary of Silk Terms, with which this bibliography opens, of considerable service.

The fifteen chapters of the bibliography itself review successively the literature of silk cultivation as it affects subsequent processing, the properties of raw silk, silk gum, and degummed silk, the preparation of nett silk yarns, the bleaching, degumming, weighting, and dyeing of silk, silk weaving and knitting, the preparation of spun silk yarn, the finishing of silk goods, the testing of silk, and uses of silk other than in textiles.

The references are conveniently grouped by chapters and are supplemented by patent, subject, and author indexes for the whole volume.

The author's specialist knowledge and experience enable the critical level of the survey to be maintained throughout, attention being directed frequently to problems of fundamental scientific and technical value on which published information is either inadequate or altogether lacking.

E. B. ABBOT

ENGLISH PATENT LAW

Inventions, Patents, and Monopolies, *by P. Meinhardt. Pp.* 352. *Stevens and Sons Limited, London.* 1946. 25*s. net.*

One rarely finds a book of law which can be read and enjoyed like a good novel. Mr Peter Meinhardt, however, can make this claim for his book on Inventions, Patents, and Monopoly. A book interesting to the legal expert and lay reader alike, it should make a particular appeal to the scientist who would like to know something of the spirit behind English patent law and its *modus operandi*. He examines the relationship between inventors and the general public and traces the development of English patent law, dealing clearly and in detail with its current practical administration.

A description of the various abuses of patent monopoly rights follows. At a time when economic reform is the order of the day and widely publicized allegations of patent abuses, often sweeping and largely inaccurate, are levelled at industrialists, the book makes a useful contribution to a clarification of the issues.

The author concludes with some suggestions for patent law reform, including an interesting one to divide patents into 'licence patents' and 'full patents,' the classification to depend upon the degree of ingenuity displayed in the invention. The monopolistic protection accorded would be likewise graded. The weight which the precedents of case law should carry in patent actions is also discussed.

L. R. BATTEN

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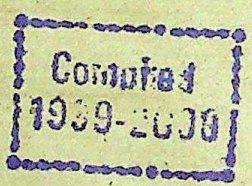

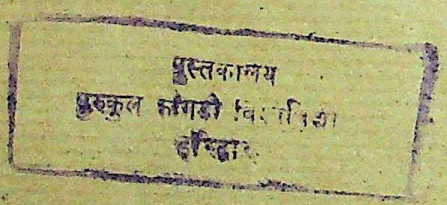

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